



1985

# Macrofossils and biostratigraphy of the Bakken Formation (Devonian and Mississippian) in western North Dakota

Lawrence C. Thrasher  
*University of North Dakota*

Follow this and additional works at: <https://commons.und.edu/theses>



Part of the [Geology Commons](#)

---

## Recommended Citation

Thrasher, Lawrence C., "Macrofossils and biostratigraphy of the Bakken Formation (Devonian and Mississippian) in western North Dakota" (1985). *Theses and Dissertations*. 297.  
<https://commons.und.edu/theses/297>

This Thesis is brought to you for free and open access by the Theses, Dissertations, and Senior Projects at UND Scholarly Commons. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of UND Scholarly Commons. For more information, please contact [zeinebyousif@library.und.edu](mailto:zeinebyousif@library.und.edu).

MACROFOSSILS AND BIOSTRATIGRAPHY OF THE BAKKEN FORMATION  
(DEVONIAN AND MISSISSIPPIAN) IN WESTERN NORTH DAKOTA

by

Lawrence C. Thrasher

Bachelor of Science, University of Maryland, 1975

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

December  
1985



OL.  
985  
T 412

This thesis submitted by Lawrence C. Thrasher in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

F. R. Holland  
(Chairman)

Alan M. Brancara

Richard D. Leber

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

---

Dean of the Graduate School

Permission

Title Macrofossils and Biostratigraphy of the Bakken Formation  
(Devonian and Mississippian) in Western North Dakota

Department Geology

Degree Master of Science

In presenting this thesis in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my thesis work or, in his absence, by the Chairman of the Department or the Dean of the Graduate School. It is understood that any copying or publication or other use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my thesis.

Signature \_\_\_\_\_

Date \_\_\_\_\_

## LIST OF ILLUSTRATIONS

### Plate

|   |     |
|---|-----|
| Macrofossils of the Bakken Formation    | 207 |
| 2. Macrofossils of the Bakken Formation |     |
| 3. Macrofossils of the Bakken Formation | 212 |
| 4. Macrofossils of the Bakken Formation | 214 |

### Figure

|  |    |
|--|----|
| Areal Extent of the Members of the Bakken Formation in the United States . . . . .   | 9  |
| 2. East-West Schematic Diagram of the Bakken Formation . . .   |    |
| 3. Approximate Areal Extent of the Bakken Formation and the Rocks of the Bakken's Depositional Complex . . . . .                   | 3  |
| 4. Correlation Chart of the Bakken's Depositional Complex . . . .  | 37 |
| 5. Location of Wells Used in This Study . . . . .  | 56 |
| 6. Faunal Occurrence Chart . . . . .   | 63 |
| 7. Generalized Cross Section of the Bakken Formation . . . . .   | 68 |
| 8. Biostratigraphic Summary of the Macrofossils of the Bakken Formation from Western North Dakota . . . . .                        | 84 |
| 9. Distribution of <u>Barroisella</u> sp. from the lower shale member of the Bakken Formation . . . . .                            | 90 |
| 10. Distribution of the Conchostracan Bed at the Top of the Lower Shale Member of the Bakken Formation . . . . .                   | 91 |
| 11. Distribution of <u>Rhipidomella missouriensis</u> (Swallow) from Unit 1 of the Middle Member of the Bakken Formation . . . . . | 92 |
| 12. Distribution of Blade-like "Leaves" from Unit 2 of the Middle Member of the Bakken Formation . . . . .                         | 93 |
| 13. Distribution of <u>Chonetes gregarius</u> Weller from Unit 3 of the Middle Member of the Bakken Formation . . . . .            | 94 |

## TABLE OF CONTENTS

|                                     |      |
|-------------------------------------|------|
| LIST OF ILLUSTRATIONS . . . . .     | vi   |
| ACKNOWLEDGMENTS . . . . .           | vii  |
| ABSTRACT . . . . .                  | viii |
| INTRODUCTION . . . . .              | 1    |
| General Purpose Scope Previous Work |      |
| GEOLOGIC SETTING . . . . .          | 8    |
| Stratigraphy                        |      |
| Lithology                           |      |
| Lower Shale Member                  |      |
| Middle Member                       |      |
| Upper Shale Member                  |      |
| Paleontology                        |      |
| Lower Shale Member                  |      |
| Middle Member                       |      |
| Upper Shale Member                  |      |
| Adjacent Rocks                      |      |
| Subjacent Rocks                     |      |
| Superjacent Rocks                   |      |
| Petroleum Geology                   |      |
| Regional Setting                    |      |
| Regional Correlation                |      |
| MATERIALS AND METHODS . . . . .     | 54   |
| Collecting Techniques               |      |
| Laboratory Techniques               |      |
| RESULTS . . . . .                   | 61   |

DISCUSSION . . . . . 74

- Intrabasinal Correlation
- Biostratigraphy
- Depositional Setting
  - Facies Control
  - Depositional Environments
  - Time Transgression

SUMMARY OF CONCLUSIONS

SYSTEMATIC PALEONTOLOGY

APPENDICES

- APPENDIX 1. Name and Location of Cores Used in This Study
- APPENDIX 2. Core Description Sheets
- APPENDIX 3. Enumeration of Collected Fossils Arranged By Well Number and Depth . . . . .
- APPENDIX 4. Code Numbers of Fossils Arranged By Taxa and Stratigraphic Setting . . . . .

BIBLIOGRAPHY 279

## ACKNOWLEDGMENTS

Thanks go to my advisor, Dr. F. D. Holland, Jr., for his suggestion of this project and for his assistance in all aspects of the study. North Dakota Geological Survey is gratefully acknowledged for the use of cores and for providing financial assistance for this study. Thanks also go to Michael D. Hayes for his enlightening discussions on the Bakken Formation and to the other members of my advisory committee, Alan M. Cvancara and Richard D. LeFever, for their comments and critical review of the manuscript. I would especially like to thank my parents, Paul and Vesta Thrasher, for their financial aid and moral support throughout this study.

## ABSTRACT

The Bakken Formation, up to 145 feet thick in North Dakota, is a subsurface formation in the Williston Basin that typically consists of two black shale members separated by a middle member of predominantly gray siltstone or silty limestone up to 85 feet thick.

Well over 500 macrofossils representing more than 50 taxa were collected from cores of 40 wells. Brachiopods, the most common fossil, represent 17 genera, 1 of which have not been previously reported from the Bakken. Nonbrachiopod fossils of this study, mostly not previously reported from the Bakken, are a hylothyrid, a conulariid, a syringoporid coral, several genera of gastropods and pelecypods, straight and coiled cephalopods, a trilobite, a conchostracan, a shrimp-like organism, pelmatozoan columns, fish fragments, trace fossils, and Foerstia sp. and other plants. Fossils not treated herein are foraminiferids, ostracods conodonts, and palynomorphs

The macrofossils of the Bakken occur mostly within five stratigraphic intervals; each interval contains a different assemblage and appears to represent a geographic extension of a previously known fauna. The basal few feet of the lower shale member locally contains a benthic rhynchonellid fauna that appears similar to fossils from near the base of Devonian black shales in the eastern United States. Foerstia sp., found in the basal 20 to 30 percent of the lower shale member in one core, appears to mark a widespread time-stratigraphic interval of Late Devonian age. The conchostracan Cyzicus (Lioestheria sp. is prolific in the upper few inches of the lower shale near the center of the basin; it is concentrated at a similar interval in correlatives of the Bakken that crop out in the Western Interior. The other fossiliferous inter-

vals of the Bakken occur in the middle member and are found in association with lithologies that are used here to divide the middle member into three stratigraphic units: units 1, 2, and 3. The lowest of these, unit 1, up to about 30 feet thick, contains a Syringothyris brachiopod assemblage similar to that of the Louisiana Limestone of latest Devonian age in the upper Mississippi Valley and in siltstones of Bakken correlatives in the western United States, also of latest Devonian age. Unit 2 is up to about 35 feet thick and is poorly fossilifer-

Blade-like "leaves" are abundant in the basal few feet of unit 2 the center of the basin, and correlate with similar "leaves" that locally abundant at the base of the Mississippian type section in Illinois. This correlation, together with the correlation of the brachiopods in units 1 and 3, suggest an early Mississippian age for unit 2. The base of unit 2, a poorly defined contact, thus appears to mark the base of the Mississippian in North Dakota. Unit 3 of the Bakken, about 5 feet thick, contains brachiopods that correlate with those of the McCraney Limestone in the type Mississippian section and the Spirifer marionensis assemblage of the Exshaw Formation in Alberta, both of early, but not earliest, Kinderhookian age; this may be the first correlation made between the McCraney and Exshaw. Macrofossils in the upper shale member are generally small, thin-shelled, and rare; no fossiliferous intervals or age-diagnostic fossils were found in this member.

The lower Bakken shale appears to have been deposited in a deep-sea during a period of worldwide rise in sea level. Unit of the middle member was deposited during a major regression and units 2 and 3 are transgressive, shallow-water deposits. The upper Bakken shale was deposited during a major, worldwide rise in sea level



## INTRODUCTION

### General

The Bakken Formation, up to 145 feet thick in North Dakota, is a subsurface formation in the Williston Basin that is generally divided into three informal members. These members consist of a lower and an upper shale, both generally dark-gray to black, carbonaceous, pyritic, and finely laminated, and a middle member of predominantly medium-gray siltstone; other lithologies of the middle member include siliceous shale, calcareous sandstone, and sandy limestone. Within North Dakota, the lower shale is the least extensive member with the other members forming an onlapping sequence above it. The shales are important petroleum source rocks in the Williston Basin, and their distinctive lithology makes them excellent marker beds for subsurface correlation within the basin.

### Purpose

This paper focuses on the macrofossils of the Bakken Formation in North Dakota which, to my knowledge, have not been described in the literature. Macrofossils from the Bakken Formation have been recovered from cores from Saskatchewan by previous workers, but they generally found the fossils to be rare. Only one study (Brindle, 1960) treated the macrofossils of the Bakken in detail; he listed eight types of brachiopods from Saskatchewan, illustrated four of them, but gave no systematic descriptions. Continued exploratory drilling, over the years, has provided an ever-increasing amount of Bakken core material available for study; it was felt that enough material was now available in North Dakota to add significantly to the knowledge of the paleontology of the formation. Because of the general lack of paleontologic

studies done on the Bakken Formation, the primary purpose of this paper is to illustrate and describe the macrofossils.

Despite the importance of the Bakken as a petroleum source rock, questions still remain concerning its age, correlation, and depositional environments. The paleontologic and sedimentological information gained from this study is analyzed in an effort to help resolve these questions. Because of the generally excellent stratigraphic control that a core study provides, and because of the Bakken's hitherto poorly documented fossil record, particular emphasis is placed on the biostratigraphy of the formation.

### Scope

The term "macrofossils" is here meant to exclude the somewhat scarce ostracods, some fragments of arenaceous foraminiferids, the paly-noflora, and the conodonts of the formation. The Bakken contains an abundant conodont fauna which was studied by Hayes (1984, 1985) and is currently being investigated by Timothy P. Huber at the University of North Dakota in Grand Forks. The emphasis of the study herein is on the macroinvertebrates of the formation, although other macrofossils, such as plants and vertebrates, are also included. Also included are juvenile forms of the macrofossils, regardless of their size

All available Bakken core material stored in the Wilson M. Laird Core and Sample Library of the North Dakota Geological Survey (NDGS) located on the campus of the University of North Dakota was used in this study. One core was found to be represented only by chips taken at one-foot intervals. This core (NDGS Well No. 413 in Dunn County) was included in this study, but the pieces were found to be too small to be of much practical value. Similarly, the sample library contains many

samples of well cuttings of the Bakken, but these were considered to be too small to lend significance to the study.

#### Previous Work

##### Lithostratigraphic Work

Kume (1963, p. 29) reported that the name Bakken was first used in 1953 by the Williston Basin Nomenclature Committee of the Saskatchewan Society of Petroleum Geologists and of the Rocky Mountain Section of the American Association of Petroleum Geologists for the thin sequence of clastic rocks occurring between predominantly carbonate rocks of the Three Forks Formation of Late Devonian age and predominantly limestones of the Madison Group of Mississippian age. The Bakken Formation was formally defined later in 1953 by Nordquist (p. 73), who designated the type section and discussed the lithology, stratigraphy, and age of the formation. Subsequent work over the next decade was done mostly by Canadian workers, who studied the Canadian, or northern, part of the Williston Basin. Using well logs, cuttings, and cores, Fuller (1956), MacDonald (1956), Penner (1958), McCabe (1959), Kents (1959), Christopher (1961 and 1962), in addition to Kume (1963) and Ballard (1963) from the United States, provided further details on the stratigraphy of the Bakken and its correlation with stratigraphically similar rocks cropping out in Alberta (the Exshaw Formation), southwestern Montana (the Sappington Member of the Three Forks Formation), and western South Dakota (the Englewood Formation). The work of the Canadian authors has been summarized by Macauley, et al. (1964).

American authors, who have worked especially on the Bakken correlatives that crop out in the western United States, have further extended the Bakken correlatives to include the Leatham Formation in northern

Utah and southeastern Idaho, the Leatham Member of the Pilot Shale in west-central Utah and east-central Nevada (formerly known as the middle member of the Pilot Shale), and the Cottonwood Canyon Member of the Madison Formation in southwestern Montana, northeastern Utah, and northwestern Wyoming; the three informal members of the Bakken Formation closely resemble a dark shale-light siltstone-dark shale sequence seen in many of these correlatives in the Western Interior. Studies made on these immediate correlatives of the Bakken Formation have been numerous; some of the works that also discussed the lithostratigraphy of the Bakken include Knechtel, et al. (1954), Sandberg (1962, 1965, and Sandberg and Mapel 1967), Macqueen and Sandberg (1970), and Sando and Dutro (1974).

A dark shale-light siltstone-dark shale sequence similar to that in the Western Interior also occurs at the systemic boundary in scattered areas in the Eastern Interior region of the North American craton. Rocks of this sequence, and especially the black shales, have been the subject of many studies over the past century, but questions still remain concerning their exact correlation, age, and depositional environment (Kepferle and Roen, 1981, p. 261). Studies on general aspects of the Devonian-Mississippian black shales used here are by Twenhofel (1939), Byers (1977), Conkin and Conkin (1979), Heckel and Witzke (1979), Conkin, et al. (1980), Demaison and Moore (1980), Ettensohn and Barron (1981), Kepferle and Roen (1981), and Kohlberger (1983).

Studies on the structural and stratigraphic setting of the Bakken in the Williston basin used here were by Sandberg and Hammond (1958), Sandberg (1964), Carlson and Anderson (1970), Meissner (1978), Bjorlie (1979), Gerhard, et al. (1982), Webster (1982), LeFever and Anderson

1984), and Hester and Schmoker 1985). Information on aspects of the petroleum geology of the Bakken was obtained from Dow 1974), Williams 1974), Meissner 1978), Webster 1982, 1984), Wilson 1983), Hester and Schmoker 1983), Krystinik and Charpentier 1984), and Price, et al 1984).

### Biostratigraphic Work

As mentioned, the only publication on macrofossils from the Bakken Formation seems to be limited to the report by Brindle (1960). He correlated (p. 16) the brachiopods of the middle member with the Syringothyris brachiopod fauna of the upper Saverton Shale and the overlying Louisiana Limestone in the type Mississippian area of northeastern Missouri and western Illinois; this correlation has been widely used (e. g., Christopher, 1961; Gutschick and Moreman, 1967) to assign an early Mississippian age to the middle member. Later conodont evidence demonstrated that the Louisiana is of latest Devonian age, however, and the systemic boundary in the Williston Basin has been more recently placed (Hayes, 1984) at the top of the middle member.

The macrofaunas of the Bakken correlatives in the Western Interior have been moderately well studied and are, in general, quite similar from locality to locality. The majority of these studies emphasized the fossils in the siltstone members of the units, because the black shale members contain few macrofossils. The macrofossils of the siltstone members that crop out in the western United States are also correlated with the distinctive Syringothyris assemblage of the upper Saverton Shale and the Louisiana Limestone. Gutschick and Rodriguez (1979, p. 37) have said that the Syringothyris assemblage zone occurs in the siltstone beds of the Sappington Member of the Three Forks Formation in

western Montana, the Leatham Formation in northern Utah, and the Leatham Member of the Pilot Shale in west-central Utah and east-central Nevada.

Most of the paleontologic work done on the Bakken correlatives in the Western Interior has been on the Sappington Member of the Three Forks Formation; studies that describe or illustrate its macrofauna include those by Gutschick, et al., (1962) and Rodriguez and Gutschick (1967, 1970). Gutschick and Rodriguez (1977, 1979) have illustrated some of the fauna from the other Bakken correlatives in the western United States and Johnson and Reso (1966) illustrated and described macrofossils from the Leatham Member of the Pilot Formation. Workers who have illustrated Devonian-Mississippian macrofossils from western Canada include Brown (1952), Brindle (1960), and Nelson (1961).

Faunal lists of Bakken correlatives in the western United States were prepared by Holland (1952) for the Sappington and for the Leatham Formations, Gutschick and Rodriguez (1967) for the Sappington, and Hose (1966) for the Leatham Member of the Pilot. Other biostratigraphic works on Bakken correlatives in the United States were by Swartz (1929), Stainbrook (1950), Robinson (1963), Gutschick and Moreman (1967), Sando, et al. (1969), Gutschick and Sandberg (1970), Conkin and Conkin (1973), and Gutschick, et al. (1976). Other paleontologic works by Canadian authors used here were by Warren (1937), Crickmay (1952), Raasch (1956), Harker and Raasch (1958), Harker and McLaren (1958), and Green (1962).

Although conodonts are not included in this study, their presence in the Bakken and its correlatives are used in regional and worldwide correlation schemes to establish the relative ages of the rock units and to locate the systemic boundary. Conodont studies used here were by Collinson (1961), Scott and Collinson (1961), Klapper and Furnish

(1962), Sandberg and Klapper (1967), Sandberg and Gutschick (1969, 1979), Sandberg (1976, 1979), Sandberg and Poole (1977), and Sandberg, et al. (1980), Sandberg (1983), and Hayes (1984, 1985).

An occurrence of an Upper Devonian palynoflora in the Bakken siltstone member in Alberta has been discussed by Macqueen and Sandberg (1970), and spores in the Sappington have been studied by Sandberg, et al. (1972). Studies on the paleontology of Devonian-Mississippian black shales, in general, considered here, were by Girty (1898, 1939), Campbell (1946), Cross and Hoskins (1951), Cross (1982), and Mathews (1983).

Works that discuss the depositional environments of the Bakken correlates were written by Gutschick and Perry (1959), Gutschick (1962) and Rodriguez and Gutschick (1975 and 1978). Additional studies on relevant paleoenvironments were reported by Conkin and Conkin (1968), Lineback and Davidson (1982), Sandberg (1983), and Sandberg, et al. (1983).

## GEOLOGIC SETTING

### Stratigraphy

Nordquist 1953, p. 70, 72) defined the Bakken Formation as a subsurface formation in the Williston Basin of southern Alberta, southern Saskatchewan, southwestern Manitoba, north-central Montana, and western North Dakota. The Williston Basin is an intracratonic, structural, and sedimentary basin that, during Bakken deposition, was a northwest-south-

trending, subsiding trough extending from western North Dakota to Alberta (Macqueen and Sandberg, 1970). Penner 1958, p. 264) noted the "obvious and exact" correlation of the three members of the Bakken in

logs from North Dakota to southern Alberta and Macqueen and Sandberg 1970, p. 41) indicated that the lower two members of the Bakken are continuous into the Alberta Basin. Bakken equivalents in Alberta have generally been assigned to the Exshaw Formation, however, and Macqueen and Sandberg 1970, p. 52) defined the western limit of the Bakken as an arbitrarily placed line running through southeastern Alberta. The areal extent of the Bakken members in the United States is shown in Figure 1.

The Bakken reaches a maximum thickness of 145 feet in the central part of the Williston Basin in North Dakota (Webster, 1982, p. 17) and generally thins out evenly toward the margins of the basin. Webster 1982, p. 9) said that the members "display an onlapping relationship with each successively younger member being more extensive than the previous one." Macauley, et al. 1964, p. 92) stated that "in Manitoba the Bakken thins out towards the east because of non-deposition of first the lower shale and then the middle sandstone, whereas the upper shale is continuous to the truncated edge of the Carboniferous." Other stud-



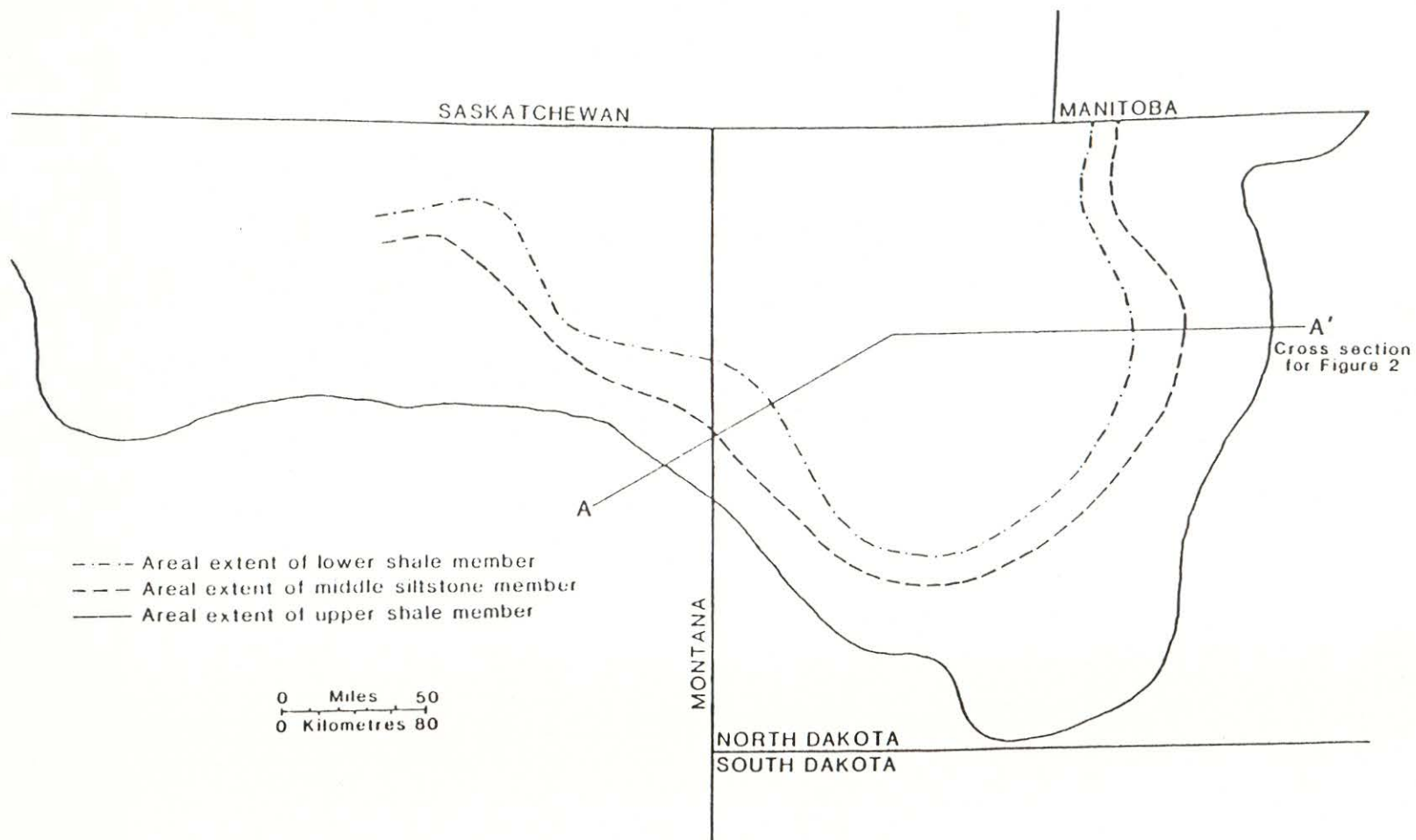


Figure 1. Areal extent of the members of the Bakken Formation in the United States (after Meissner, 1978, with slight modifications by Webster, 1982). Bend in line of cross section is near the thickest part of the Bakken.

ies (e. g., Sandberg and Hammond, 1958; Kume, 1963) have suggested that the pinching out of the lower and middle members may be at least partly due to early Mississippian erosion as well. The thickness and stratigraphic relations of the Bakken members, as determined by Meissner (1978), are shown in a schematic cross-section of the Bakken Formation in Figure 2

The name of the Bakken Formation was derived from the Amerada Petroleum Corporation, H. O. Bakken No. 1 well (NDGS Well No. 32), SW 1/4, NW 1/4, sec. 12, T. 157 N., R. 95 W., located near the occurrence of the thickest section of the formation, just to the east of the Nesson anticline in Williams County, North Dakota. The strata between 9615 feet and 9720 feet in this well were formally designated by Nordquist (1953, p. 72) as the type section of the Bakken. The general lithology of the Bakken is remarkably homogeneous over an area exceeding 50,000 square miles (Fuller, 1956, p. 18) and the unique lithologic characteristics of the formation make the Bakken easily detectable on well logs. Fuller said (p. 18) that these factors make the Bakken Formation the most reliable marker unit for general, subsurface litho-correlation in this part of the column for more than one-half of the basin.

Fuller (1956), Christopher (1961), and Kume (1963) have found that the Bakken becomes difficult to recognize, and thus to trace, near the margins of the formation, where the lower shale member is generally absent. Near the margins of the formation in Canada, the black shale members of the Bakken grade into red and green shales and the middle member becomes coarser grained and contains more primary bedding structures, such as current bedding and ripple marks (Fuller, 1956; Christopher, 1961). Fuller (1956, p. 22) stated that this abundance of

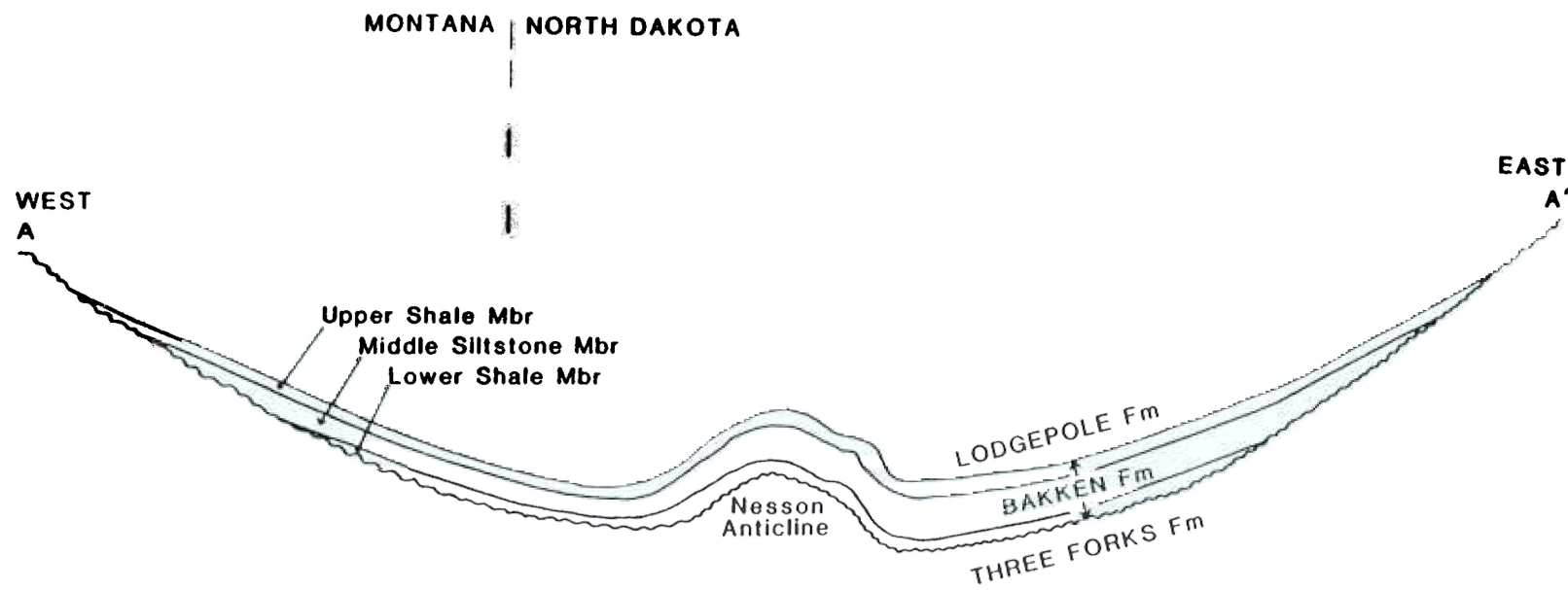


Figure 2. East-West schematic diagram of the Bakken Formation (adopted from Meissner, 1978). Refer to Figure 1 for line of cross section.

sedimentary structures, "when coupled with the general increase of abundance and coarseness of the sand, suggests proximity to the contemporary shoreline." Lithic changes similar to those found in Canada have been reported by Ballard (1963) to occur near the eastern margin of the Bakken Formation in North Dakota. Kume (1963, p. 39) defined the shelf area of the Bakken as the area around the margins of the formation in which the lower shale member is typically absent; he designated this area the "Marginal Shelf" because this area is "thought to be the general marginal area of the Bakken sea." Both Fuller (1956) and Kume (1963) used the term "Central Area" to describe the Bakken Formation where it occurs in its typical lithology and tripartite succession which Kume (1963, p. 44) thought "to represent the general area occupied by the seaway."

### Lithology

#### Lower Shale Member

The lower shale member of the Bakken Formation, which has been informally called the "Exshaw shale member" by Canadian workers, reaches a maximum thickness of 50 feet in a well-developed depocenter in west-central Mountrail County, North Dakota (Webster, 1982, p. 19). The member generally thins out evenly toward the margins of the basin and throughout its extent, overlies the Three Forks Formation, or, in Canada, equivalents of the Three Forks (the Big Valley or Palliser Formation). Webster (1982, p. 9) said that the lower shale member in North Dakota is overstepped by the middle member near the margins of the basin and that the limit of the member may have been modified by erosion prior to, or during, deposition of the middle member. Although generally absent in the marginal shelf area, Webster (1982, p. 19) found local

thickenings of the member near the eastern limit of the formation in North Dakota and Fuller 1956, p. 20) and Christopher 1961, pl. 5) reported that the lower member occurs over the northwestern part of the Marginal Shelf in southwestern Saskatchewan and southeastern Alberta.

The lower shale member typically consists of black to dark gray or dark brown shale that is well indurated, carbonaceous, pyritic, siliceous, and very finely laminated (Webster, 1982, p. 23). The shale is generally fissile but often breaks with a conchoidal fracture which Webster said (p. 23) is probably due to the high quartz content of the rock. The pyrite occurs as concretions or as finely disseminated particles that are commonly concentrated into the laminae. A few thin beds of dark gray, finely to coarsely crystalline limestone, up to about three feet thick, were found to occur at various intervals in four cores of the lower shale member by Hayes 1982, p. 54). During this study, such limestones were found in eight cores (NDGS Well Nos. 607, 793,

1405, 1748, 2602, 4340, and 8069), but as these limestones did not yield fossils, their extent or significance is not treated herein. The minor color variations seen in the shales appears to be due to the amount of silt or clay versus the amount of carbon present (Macqueen and Sandberg, 1970, p. 39; Hayes, 1984, p. 53). Webster 1982, p. 25) reported that the organic carbon of the Bakken is not concentrated into the laminae but, rather, is distributed rather evenly throughout both of the dark shale members; he said (p. 23) that the carbon makes up an average of 11.33 percent of these rocks by weight. Kents 1959, p. 18)

that the organic material of the dark shales has a relatively high level of radioactivity due to its high content of isotopes of potassium, thorium, or uranium. He said further (p. 18) that this radioactivity

makes the shales particularly easy to detect on gamma ray logs, as the radioactivity is from two times to more than ten times that of the stratigraphically adjacent rocks in the geologic column.

Toward the marginal shelf area, the lower shale member becomes carbonaceous and more clayey, silty, and dolomitic (Meissner, 1978, p. 209), and begins to lose its characteristic features. Fuller (1956, p. 20) and Christopher (1961, p. 41) said that the lower shale grades into pale green and reddish variegated shales in the northwestern shelf area that closely resemble the shales of the underlying Three Forks Formation.

Christopher (1961, p. 42) and Meissner (1978, p. 209) have indicated that the lower shale member is unconformable with the Three Forks Formation throughout the basin, although Webster (1982, p. 15) and Hayes (1984, p. 91) found that the Three Forks-Bakken contact appears conformable in cores from the deeper parts of the basin in North Dakota. Evidence of a hiatus between these two units in Canada cited by Christopher (1961, p. 42) is the thinning trends of the Three Forks equivalents (Big Valley Formation), the sharp contacts between the two units as seen in cores, the locally weathered surface of the Big Valley Formation, and by a thin pebble bed at the base of the black shale member. Fuller (1956, p. 23) said that this pebble bed underlies much of the lower shale member in Canada, becomes better developed toward the shelf area where it reaches a maximum development of about two inches, and contains crushed black shale, brown phosphatic fragments, and pebbles of finely crystalline dolomite set in a matrix of siltstone that is, in places, sandy or rich in conodont fragments. It is the presence of this pebble bed in the northwestern shelf area that Fuller (1956, p. 20) used to disting-

uish the lower shale member from the Three Forks Formation. Hayes (1984, p. 60, 61 found a sandstone bed about one inch thick at the base of the lower shale member in one core from near the southern margin of the basin in North Dakota (NDGS Well No. 9351 in Billings County), other occurrences of such a pebble bed in North Dakota have not been noted by Kume (1963), Webster 1982), Hayes (1984), or in this study.

#### Middle Member

The middle member of the Bakken Formation, which was informally called the "Coleville sand" by Canadian workers (Kume, 1963, p. 41), was found by Webster 1982, p. 19) to reach a maximum thickness of 85 feet in North Dakota. The member generally thins out evenly toward its margins, although Fuller (1956) and Meissner 1978, p. 209) found the member to have a more variable thickness than the black shale members of the formation. The middle member overlies the lower shale member throughout its extent and lies unconformably on the Three Forks Formation in the marginal shelf areas; over the shelf areas in Canada, the middle member was said by Fuller 1956, p. 23) to be separated from the Three Forks by a continuance of the pebble bed that underlies the lower shale member. Webster (1982, p. 19) reported that the middle member is, generally, structurally parallel with the underlying rocks in that it has a well-defined depocenter, but that its upper surface is flat, gesting to him (p. 23) that "subsidence in the area of the formation depocenter was reduced during this time." Webster (1982, fig. 11) and Hester and Schmoker (1985, map C) mapped the depocenter of the middle member as being slightly offset to the northwest of that of the lower shale member. Webster (1982, p. 9) suggested that the extent of the middle member in North Dakota represents the general depositional limits

of the member, although Kume 1963, p. 47) said that the absence of the member in the southern shelf area may be due to erosion. Fuller 1956 p. 17) indicated that the northern boundary of the member is truncated by pre-Jurassic erosion.

Although predominantly a hard, gray siltstone, the middle member consists of many other lithologies; it was described by Christopher 1961, p. 46) as a "multifacies relationship of poorly and well sorted sandstone, siltstone, shale, laminated shale, siltstone and sandstone, oolitic calcarenite and limestone." Dolostone has also been reported (e.g., Webster, 1982, p. 25). Petrographic studies by McCabe (1959, p. 22) showed that the sandstone and siltstone are composed almost entirely of quartz with minor amounts of feldspar and with a siliceous, calcareous, or dolomitic cement. The grains range in size from coarse silt to very fine sand, and are moderately to well rounded for their size. Although the sorting is quite variable, Nordquist (1953, p. 74) reported that the grain size of the middle member coarsens toward the northwestern marginal area and that the middle member grades into a fine-grained dolostone near the southern boundary in North Dakota. Thus, he concluded, "The clastic ratio of the formation increases northward into southern Canada and a source in that direction is indicated." McCabe (1959, p. 22) classed the middle member petrographically as a "dolomitic argillaceous sandy quartzose to slightly feldspathic siltstone." Fuller (1956, p. 18) stated that the middle member also contains abundant pyrite and in some places "a pale green glauconite-like silicate." The porosity and permeability of the middle member are generally low, due to cement filling the intergranular pore spaces (Webster, 1982, p. 28)

Christopher 1961 used well cores from southern Saskatchewan to



develop stratigraphic subdivisions of the middle member. Based on lithology, he designated (p. 46) two main zones (an "A bed" underlying a "B bed"), and further divided the "B bed" into four interfingering units (in ascending order, B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, and B<sub>4</sub>). He described the "A bed" as a massive, medium-gray to greenish-gray, very calcareous, fossiliferous, pyritic, silty, very fine-grained sandstone to siltstone, about 10 to 35 feet thick. Bedding was said to be rare and where present, disrupted. Christopher noted (p. 46), "The fossils, consisting almost wholly of calcitic brachiopod shells, are generally restricted to the bottom 5-10 feet."

Christopher 1961, p. 46) reported that each of the "B bed" sub-units consists predominantly of one lithology. The "B<sub>1</sub>" and "B<sub>3</sub>" units were said to be composed of unfossiliferous, dark gray shale that becomes silty and grades into siltstone and sandstone on the eastern shelf. These predominantly shaly units interfinger with the sandstone beds of the "B<sub>2</sub>" and "B<sub>4</sub>" units. The "B<sub>2</sub>" unit was described by Christopher 1961, p. 46) as an unfossiliferous, thin-bedded, friable, fine- to medium-grained sandstone, 10-15 feet thick, which graded laterally into a "well cemented, very calcareous, medium grained sandstone and oolitic calcarenite . . . toward the west, and into a coarsely crystalline limestone in the northwestern shelf area. The "B<sub>2</sub>" unit was said by Christopher 1961, p. 46) to contain "well developed cross-bedding, ripple marks, current scour marks, and numerous diastems." The "B<sub>4</sub>" bed occupies the top 5 to 15 feet of the middle member and is similar to the "A bed" in that it is a predominantly massive siltstone that contains calcitic brachiopods scattered throughout. Although there has been little attempt to use Christopher's stratigraphic scheme in North

Dakota, Webster (1982, p. 24), in his stratigraphic column, indicated that brachiopods typically occur in about the bottom 25 feet and top eight feet of the middle member, thus suggesting that Christopher's "A bed" and "B<sub>4</sub>" bed extend into North Dakota.

In other stratigraphic work on the middle member in Canada, Kents (1959, p. 19) mapped a biostromal limestone that occurs in the bottom 2 to 4 feet of the middle member in an area of about 1000 square miles in southwestern Saskatchewan. He said (p. 19) that this limestone contains fossil debris and oolites, is occasionally conglomeratic, and occupies the same stratigraphic position as does a dolomitic siltstone bed traced by Penner (1958) in southeastern Alberta, which Penner treated as a fourth Bakken member.

Hayes (1984, p. 92) indicated that the middle member of the Bakken Formation is conformable with the lower shale member in North Dakota but Christopher (1961, p. 42) said that a disconformity appears to separate the two members in Saskatchewan. Evidence Christopher cited (p. 42) for this disconformity includes the pebble bed at the base of the middle member and the presence of oxidized shale and fissures ("mud cracks") filled with sandstone within the top few feet of the lower shale member near the eastern limit of the member. Kents (1959, p. 19) and Christopher (1961, p. 47) found evidence that the lower beds of the middle member disappear first toward the margins of the basin in Canada.

Christopher (1961, p. 47) said that the A bed appears to be the least extensive unit of the middle member in Saskatchewan and, in speaking of this member, Kents (1959, p. 19) said, "The writer is of the opinion that where sediments are less than 40 feet thick, it is a result of non-deposition of some of the lower beds of the member." Such a disappear-

ance of the lower beds in North Dakota was indicated in the schematic cross-section of the Bakken Formation by Meissner 1978), which is displayed in this report as Figure 2

### Upper Shale Member

The upper shale member is the thinnest, but most extensive, member of the Bakken Formation in North Dakota (Kume, 1963, p. 38; Webster, 1982, p. 22). Webster 1982, p. xi reported this member to have a maximum thickness of 23 feet in North Dakota and said that the member has a more even thickness distribution with a broader, less well-defined depocenter than the other two members. Throughout most of the shelf area in the United States, the upper member oversteps the middle member and lies unconformably on the Three Forks Formation before pinching out (Meissner, 1978, p. 209). The lateral extent of the upper shale member in North Dakota, like the middle member, was thought by Webster 1982, p. 9) to represent the general depositional limits of the member. Sandberg and Klapper 1967, p. B38) stated, "because of later erosion, the upper black shale of the Bakken now extends only as far west as north-central Montana." Kents 1959, p. 21) said that the upper shale member is poorly developed or absent in southwestern Saskatchewan but pointed out

Penner 1958) found the member to be well developed in southeastern Alberta. Fuller 1956, p. 17 indicated that the northern boundary of the upper shale member in Saskatchewan is truncated by pre-Jurassic erosion and Macauley, et al. 1964, p. 92), said that the upper shale mem-

in Alberta grades northwestward into black and dark gray, noncarbonaceous shales that appear indistinguishable from basal dark shales of the overlying Banff Formation.

Sandberg and Klapper 1967, p. B39) reported that the upper shale

member crops out near its southern margin in the Little Rocky Mountains of north-central Montana and indicated that this is the only known surface exposure of the Bakken Formation. This shale was named the Little Chief Canyon of the Lodgepole Formation by Ketchel, et al. (1954), but this name was formally abandoned by Sando and Dutro (1974, p. 3) since Sandberg and Mapel (1967, figs. 2 and 10) had recognized the shale as belonging to the Bakken Formation. Meissner (1978, p. 209) pointed out, however, that Nordquist (1953) formally defined the Bakken formation as occurring only within the subsurface of the Williston Basin; the Little Rocky Mountains were mapped by Sandberg and Mapel (1967, fig. 1) as being just outside the area of the basin.

Meissner (1978, p. 209) said that, in the Central Area, the lithology of the upper member is apparently identical to the dark shales of the lower member. In thin section, Meissner (1978, p. 209) found the shale "to be composed mostly of indistinct organic material with lesser amounts of clay, silt, and dolomite grains"; Webster (1982, p. 25) reported scattered grains of detrital quartz and some calcite to be present also. Thin beds (less than one inch) of siltstone or sandstone, some conodont-bearing, were reported by Hayes (1984) to occur in the upper shale member in North Dakota.

Kents (1959, p. 21) indicated that the upper Bakken shale becomes more silty and less carbonaceous toward the margins of the basin in Canada. Christopher (1961, p. 48) said that the member is oxidized to red in Saskatchewan and Ballard (1963, p. 18) said that the member is gray, reddish, or yellowish in several places in the eastern marginal area of the Bakken Formation in North Dakota.

The upper shale member was said by Kents (1959, p. 19) and Christo-

pher 1961, p. 48) to have a sharp contact with the middle member with no evidence of an unconformity. Webster (1982, p. 9) and Hayes 1984, p. 62, 92) found that both the lower and the upper contacts of the upper shale member in North Dakota generally appear conformable.

## Paleontology

### Lower Shale Member

Previously reported macrofossils from the lower shale member of the Bakken Formation consist of Lingula sp. by Fuller 1956, p. 50), possible fish scales by Kume 1963, p. 46), and Christopher (1962, p. 75) reported that chonetid brachiopods are less common in the lower shale than in the upper one. In his paleontologic study of the Bakken Formation, Brindle 1960, p. 16) reported that Rhipidomella missouriensis occurs in the lower shale member but Christopher (1961, p. 19) said that Brindle had meant to say that this species was found in the middle member; thus, Brindle evidently found no macrofossils in the lower shale member in Saskatchewan. Webster (1982, p. 28) found that conodonts are the most common fossils in the black shales of the Bakken in North Dakota and that amber-colored tasmanitid spore cases are locally abundant. Conodonts have been collected and identified from one well in southeastern Alberta (Macqueen and Sandberg, 1970, p. 52) and from a number of cores from western North Dakota by Hayes 1984, 1985).

### Middle Member

Relatively few fossils have been reported from the middle member of the Bakken Formation. Fuller (1956, p. 18) said that the fossils of the middle member in southern Saskatchewan consist of "a scanty fauna restricted to heavily pyritized, finely ribbed brachiopods, Lingula, and

occasional crinoid ossicles." Christopher 1962, p. 74) said that the fossils of the middle member in southern Saskatchewan consist mostly of calcitic brachiopods and indicated 1961, p. 57) that the brachiopods become more abundant southward, toward North Dakota. Brindle (1960, p. 16) reported the occurrence of Rhipidomella missouriensis, Spirifer cf. S. osagensis, and Spirifer sp. from the middle member in Saskatchewan. Ballard 1963, p. 18) commented that pyritized brachiopods are common in the middle member in western North Dakota, and Kume 1963, p. 47 reported Orbiculoidea sp., a possible Cyrtospirifer sp., and Camarotoecia sp. from cores in the same area. Webster 1982, p. 24) indicated that brachiopods are typically abundant in the bottom and top beds of the middle member in North Dakota and that bioturbation is common in the lower part of the member. Kents 1959, p. 19) reported conodont fragments to be common in the middle member in Saskatchewan, but other studies have indicated that conodonts are rare or absent in this member; Hayes (1984, p. 65) collected five indeterminate fragments of ramiform elements from cores from North Dakota. Other micropaleontological work on the middle member consists of the fossil spores that were collected and identified from one well in southeastern Alberta (Macqueen and Sandberg, 1970, p. 52).

#### Upper Shale Member

As in the lower Bakken shale, and indeed in all the Upper Devonian-Lower Mississippian black shales, macrofossils have been generally reported to be scarce in the upper shale member. Brindle 1960, p. 16) found that brachiopods are the most common macrofossils of this member; these consist of three inarticulates (Lingula sp., Orbiculoidea capax, and Crania sp. and two articulates (Chonetes sp. and Rhipidomella sp.)).

Kume 1961) reported a specimen of Conularia from the upper shale member in one core (NDGS Well No. 207) from near the eastern margin of the formation in Wells County; this specimen has been incorporated into this study but Bjorlie 1979, p. 45) and Webster (1982, p. 23) have indicated that this core represents the Carrington shale facies of the Lodgepole Formation. The only other macrofossil reported from the upper shale member is a woody plant fragment collected by Webster 1982); this plant has also been incorporated into this study. As in the case of the lower member, conodonts and spores are the most commonly reported fossils of the upper shale; conodonts from several cores of the upper Bakken shale from western North Dakota have been collected, identified, and illustrated by Hayes 1984).

#### Adjacent Rocks

##### Subjacent Rocks

The Three Forks Formation, of Late Devonian age, averages about 150 feet thick in North Dakota (Meissner, 1978, p. 209) and underlies the Bakken everywhere in the Williston Basin. Webster 1982, p. 15) said that the Three Forks in North Dakota reaches a maximum thickness of about 250 feet in the central part of the basin and that the two formations appear conformable and structurally parallel in the center of the basin but that, near the margins, the upper beds of the Three Forks are truncated and an angular unconformity separates the two. Sandberg and Hammond 1958, p. 2322-2324) said the Three Forks occurs in the subsurface throughout the Williston Basin, north-central and south-central Montana, and occurs in outcrop in scattered areas throughout the Rocky Mountain region in northern Wyoming and southwestern Montana.

The Three Forks was formally divided by Sandberg (1965) into three

members throughout most of its extent in Montana. The lower member was named the Logan Gulch Member, and it consists of predominantly gray dolomite and anhydrite. The Logan Gulch is overlain by the Trident Member, which consists mostly of interbedded red and green dolomitic shales. In southwestern Montana, the Trident is overlain by the black shale and siltstone sequence of the Sappington Member of the Three Forks Formation. Sandberg 1965, p. N11, N13) reported that the Logan Gulch and Trident Members are continuous with, respectively, the Stettler Big Valley (or Palliser) Formations of the Wabamun Group in southern Alberta, where they underlie the Exshaw and Bakken Formations

The Three Forks Formation in North Dakota has not been subdivided into members although its rocks closely resemble those of the Big Valley and Trident Members in Montana. A subsurface reference section for Three Forks was suggested by Sandberg and Hammond 1958, p. 2324 for the rocks occurring between the depths of 10,076 feet and 10,310 feet in the Mobil Producing Company's Birdbear No. 1 well, NDGS Well No. 793, in Dunn County, North Dakota (SE 1/4, NE 1/4, sec. 22, T. 149 N., R. 91 W.). The upper part of the Three Forks in North Dakota consists predominantly of pale green or red dolomitic shales that are interbedded in a manner similar to that of the Trident Member in Montana. Other lithologies of the Three Forks in North Dakota include gray, dolomitic sandstone and light gray siltstone (Kume, 1963, p. 32). In scattered areas in North Dakota, the uppermost bed of the Three Forks consists of white slightly calcareous siltstone or very fine- to fine-grained sandstone 5 to 15 feet thick. This bed is informally called the "Sanish" sandstone and locally produces oil; Kume (1963, p. 33-34) reported that the distribution of this sandstone is "erratic and not continuous for any great



distance."

In a manner similar to that of the Bakken Formation, the Three Forks becomes increasingly interbedded with red, dolomitic shales toward its margins and grades into redbeds in the marginal shelf area. These beds of red shale, siltstone, and dolomite were once called the Lyleton Member of the Three Forks but this term was abandoned by Sandberg and Hammond (1958, p. 2327) because they recognized the red beds as a near-shore lithofacies of the Three Forks Formation.

Macrofossils of the Three Forks consist largely of brachiopods of the Cyrtospirifer monticola fauna of Late Devonian (Late Famennian) age (Sandberg and Mapel, 1967, p. 868). This is a distinctive fauna that is not known to occur in beds younger than the Three Forks Formation (Gutschick and Rodriguez, 1967, p. 606). This brachiopod assemblage is associated with the Upper Scaphignathus velifera conodont zone of Late Famennian age (Sandberg and Gutschick, 1979, p. 123).

#### Superjacent Rocks

The Bakken is overlain everywhere by the Lodgepole Formation of the Madison Group, or, in southeastern Alberta, by the Banff Formation, the equivalent of the Lodgepole. The Lodgepole Formation and the overlying Mission Canyon Formation comprise the thick, extensive Mississippian (lower Kinderhookian-lower Meramecian) limestones of the Madison Group. The Madison is one of the most extensive rock-stratigraphic units in the western United States; it extends from North Dakota, through Montana and northern Wyoming, into eastern Idaho and northeastern Utah, and occurs in outcrop in scattered areas of Wyoming, Montana, and the Canadian Rocky Mountains. In the Williston Basin, the Madison Group also contains the Charles Formation, which is an evaporitic rock unit up to

about 800 feet thick that overlies the Mission Canyon Formation

The type section of the Madison is near the town of Logan in southwestern Montana, and type sections of the Lodgepole and Mission Canyon Formations are in the Little Rocky Mountains of north-central Montana (Sando and Dutro, 1974, p. 1). Sando and Dutro (1974, p. 2) reported that the Lodgepole is divided into two members throughout most of its area of occurrence in Montana: a generally dark, shaly, laminated limestone called the Paine Member and an overlying lighter colored, fossiliferous, massive limestone called the Woodhurst Member. A third member, the Cottonwood Canyon Member, is a predominantly clastic unit that underlies the Paine Member in southwestern Montana; this member is a partial equivalent of the Bakken Formation.

The Lodgepole in North Dakota is up to 900 feet thick (Webster, 1982, p. 13), and consists (p. 2) of "dense dark gray to brownish-gray limestone and dark gray calcareous shale. The lowermost beds in contact

the Bakken in North Dakota commonly consist (Webster, 1982, p. 13) of "a medium gray to brownish gray, dense limestone that is fragmental in some places, and has abundant pelmatozoan material." LeFever and Anderson (1984, p. 31-32) reported that the Lodgepole is conformable

the Bakken Formation in the central portion of the basin and that the Lodgepole truncates progressively older rocks along the eastern margin of the basin.

A dark gray to black shale or carbonaceous limestone, up to about 90 feet thick, that has electric log characteristics similar to those of shales of the Bakken is found locally near the bottom of the Lodgepole; this dark rock unit is usually separated from the Bakken by several feet of limestone (Webster, 1982, p. 13) but, in some areas of southwestern

Manitoba, McCabe 1959, p. 22) found that this unit directly overlies the upper shale member of the Bakken Formation and can only be distinguished from the Bakken by the slightly greater radioactivity of the latter. In the eastern shelf area, this unit is known as the Carrington shale facies in North Dakota, and as the Routledge shale facies in Canada and in Rolette County, North Dakota (Bjorlie, 1979, p. 10-11). Webster 1982, p. 13) indicated that a similar dark shale unit occurs sporadically throughout much of the central part of the Williston Basin in western North Dakota. Fuller (1956, p. 26) reported that this unit in southwestern Manitoba contains a Lingula-conodont fauna similar to that of the Bakken dark shales

Fossils are generally common in the Lodgepole and Mission Canyon limestones and numerous taxa, including brachiopods, corals, foraminiferids, algae, and conodonts, have been used to establish a number of biostratigraphic zonation schemes. These zones are generally complementary to one another and supplement each other where guide fossils of a particular zonation scheme are missing (Sando, et al., 1969; Sandberg et al., 1983, p. 707).

#### Petroleum Geology

The Bakken Formation is of interest to the oil industry, as the carbonaceous shales within the formation have been shown (Dow, 1974; Williams, 1974) to be excellent petroleum source rocks. The carbonaceous material, consisting mostly of kerogen, is more than ten times the amount needed for petroleum source rocks (Hester and Schmoker, 1983, p. 2169). Webster 1984, p. 72) reported that the kerogen in the black shales of the Bakken breaks down into oil and other nonhydrocarbon organic molecules when subjected to enough heat and time. Using geo-

chemical methods, he concluded (1984, p. 72) that this thermal maturation of the Bakken shales occurs in the Williston Basin at depths of about 9,000 feet or deeper, where the temperature would probably be above 100 degrees Celsius. Meissner 1978, p. 212), however, had concluded that, on the basis of sonic log properties, the critical temperature could have been reached at about 6,500 feet and, on the basis of the color of conodonts, Hayes 1984, p. 82) suggested that oil generation may have occurred at 7,500 feet. Price, et al. (1984) suggested that variable heat flow in the Williston Basin may have caused hydrocarbon generation to occur at different depths (between 7,500 feet and 10,000 feet in different areas of the basin

Sometime after oil genesis began, the black shales became saturated and overpressured with oil due to the low permeability of the Bakken Formation and the relatively impermeable rocks of the Three Forks and Lodgepole Formations. Fracturing of the rocks became the principal means for Bakken oil expulsion, which led to the oil migrating both up and down in the section (Webster, 1982, p. 87)

The oil from the Bakken Formation is classified geochemically as Type II oil, and the Bakken is the only known source of Type II oil in the Williston Basin (Williams, 1974). Type II oil is found in large amounts in the Madison Group and in lesser amounts in the underlying Three Forks and Birdbear Formations. Webster 1982, p. 87 reported that lateral migration has occurred underneath stratigraphic seals in the upper Mission Canyon and at the base of the Charles Formation, and thus oil originating from the Bakken is produced in areas outside the Bakken's areal limits of thermal maturation. Wilson (1983, p. 108) said that production from the Bakken Formation is limited to the area that

Webster (1982) determined to be thermally mature (below 9,000 feet), and thus he concluded that the oil has not migrated a significant amount within the Bakken itself, due to the impermeability of the formation.

Because of the generally low permeability of the Bakken Formation best oil production from the Bakken Formation in North Dakota occurs in the areas of high curvature of structures, where the maximum amount of fractures is most likely to occur (Webster, 1982, p. 38). Webster (1982, p. 35) reported that the flanks of the Nesson anticline are the principal area of Bakken production with most production coming from the Antelope field on the southeastern flank of the anticline. Another area of Bakken production in North Dakota mentioned by Webster (1984, p. 64) is along the flanks of the Cedar Creek anticline. In Canada, the Bakken produces oil locally in Saskatchewan near the town of Coleville. Kents (1959, p. 19) reported that this production in Canada comes from the Bakken middle member, where "some of the carbonate has been leached out leaving the rock poorly packed, highly porous, and quite friable

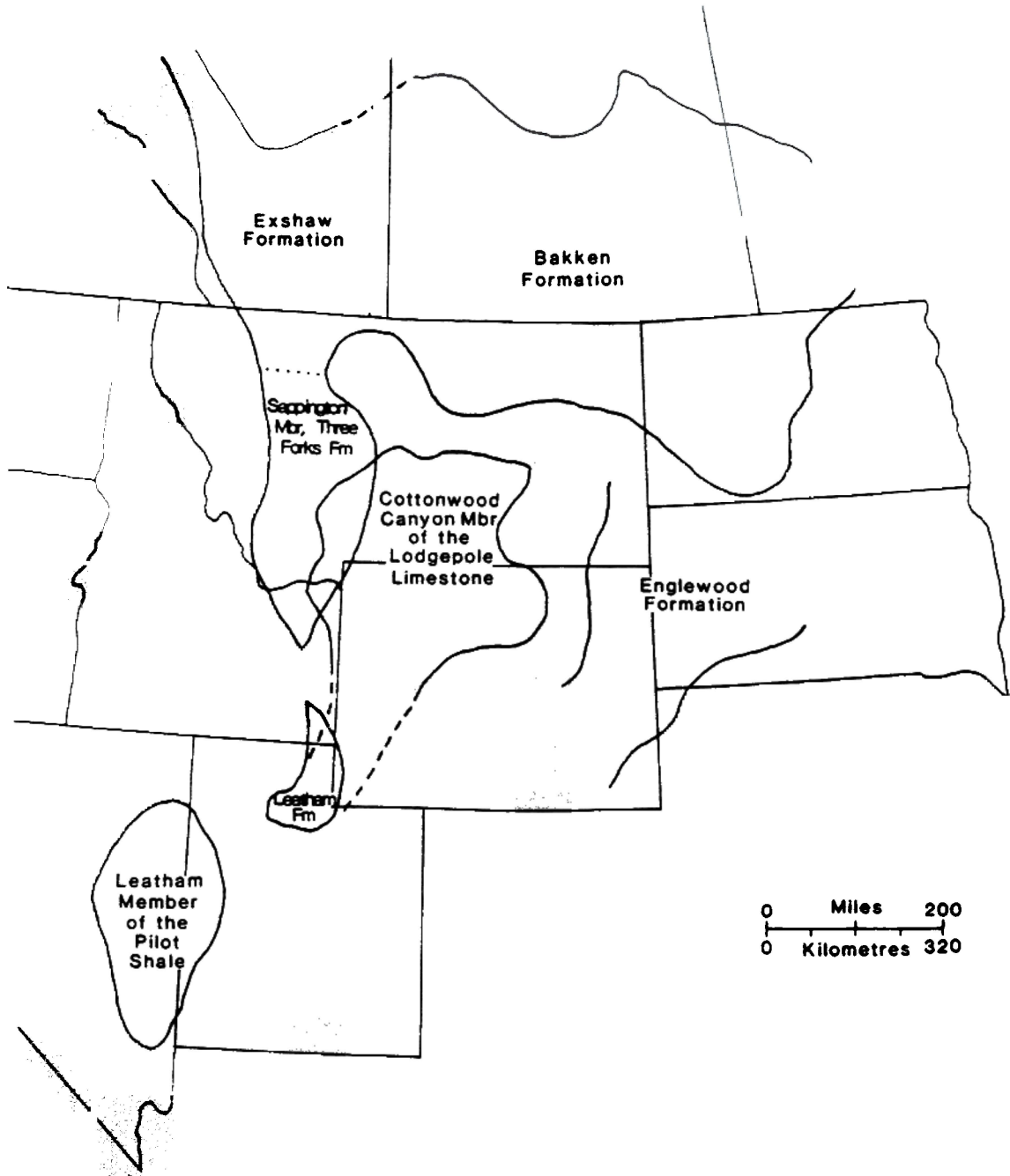
#### Regional Setting

Sandberg and Mapel (1967, p. 869) and Gutschick and Rodriguez (1979, p. 37) have indicated that the Bakken is part of a thin, partly continuous depositional complex of seven clastic units in the Western Interior, and that these units were deposited penecontemporaneously in discrete basins between areas of relative uplift during the time of the Late Devonian-Early Mississippian Antler Orogeny. The location of these

units is shown on Figure 3. These clastic units closely resemble one another in thickness, distribution, and stratigraphic occurrence

although each rock unit contains unconformities, when taken together they represent nearly continuous deposition across the Devon-

Figure 3. Approximate areal extent of the Bakken Formation and the rocks of the Bakken's depositional complex (see text). Adopted from Hayes (1984); primary sources are Christopher (1961) and Meissner (1978) for the Bakken Formation, Macqueen and Sandberg (1970) and Gutschick and Rodriguez (1979) for the Exshaw Formation, Sappington Member of the Three Forks Formation, Leatham Formation, and Leatham Member of the Pilot Shale, Sandberg and Klapper (1967) for the Cottonwood Canyon Member of the Lodgepole or Madison Limestone, and Sandberg and Mapel (1967) for the Englewood Formation.



ian-Mississippian boundary.

As mentioned, the tripartite succession of the Bakken Formation is similar to a dark shale-light siltstone-dark shale sequence found in many of the rocks of its depositional complex. The upper dark shale member of this lithic sequence in the Western Interior has an unconformable relationship with its underlying rocks and truncates the lower black shale and light siltstone members of the complex (Sandberg and Mapel, 1967, p. 874). For this reason, the upper shale members are commonly grouped with the overlying Lower Mississippian carbonates, whereas the lower and middle members are, in places, grouped with the underlying Upper Devonian rock units. Rock units of the Bakken's depositional complex that consist of a black shale member overlain by a light siltstone member and thus correlate with the lower two members of the Bakken Formation are the Exshaw Formation, the Sappington Member of the Three Forks Formation, the Leatham Formation, and the Leatham Member of the Pilot Shale (Sandberg and Gutschick, 1979). The upper black shale member in the Bakken's depositional complex is called the Cottonwood Canyon Member of the Lodgepole or Madison Limestone where it overlies the Sappington Member or the Leatham Formation, and the basal shale of the Banff Formation where it overlies the Exshaw.

Macqueen and Sandberg 1970, p. 41) and Sandberg and Poole 1977, p. 172) have determined, by means of regional correlation studies of measured sections and wells, that the lower black shale and siltstone members of the Bakken's depositional complex were originally depositionally continuous rock bodies that were partly separated by Early Mississippian erosion. Sandberg 1965, p. N16-N17) reported that the lower black shale and medial siltstone members of the Bakken are continuous



with the corresponding rocks of the Exshaw Formation and that the black shale of the Exshaw is, in turn, continuous with the black shale of the Sappington Member. Sandberg and Klapper (1967, p. B38) reported that the siltstone units of the Exshaw and Sappington are now separated by an erosional area about 40 miles wide in northwestern Montana. Sandberg and Poole (1977, p. 172) said that Early Mississippian erosion has completely isolated the Leatham Formation and the Leatham Member of the Pilot Shale from other rocks of the complex. They also said (p. 172) that "the once depositionally continuous" siltstone members of the Sappington Member of the Three Forks Formation (hereafter referred to as the Sappington Member), the Leatham Formation, and the Leatham Member of the Pilot Shale (hereafter referred to as the Leatham Member) have, in general, "smaller dimensions than the corresponding areas of the [black shale members] because of the effects of Early Mississippian erosion

Sandberg and Klapper (1967, p. B37) reported that the dark clastic rocks of the Cottonwood Canyon Member of the Lodgepole Formation (hereafter referred to as the Cottonwood Canyon Member) in western Montana and northern Utah grade eastward into predominantly carbonate rocks that closely resemble the "lithologic character, stratigraphic relations thickness, and age" of the Englewood Formation. They said (p. B37) that the Cottonwood Canyon Member and the Englewood Formation are separated from each other by about 30 miles in northwestern Wyoming and that this separation may be due to Early Mississippian erosion.

Gutschick and Moreman (1967, p. 1009) said that the dark shale-light siltstone-dark shale sequence is the most common of four general types of sedimentation that straddle the Devonian-Mississippian boundary throughout the North American craton. This sequence occurs around the

eastern and western margins of the cratonic platform, in subsiding troughs adjacent to the Transcontinental Arch, and in intracratonic basins, such as the Williston and Michigan Basins. Gutschick and Moreman (1967, p. 1016) reported that rock units of this type of sedimentation in the eastern and central United States include the Ohio Shale, New Albany Shale, Antrim Shale, Chattanooga Shale, and the Woodford Formation. They reported further (p. 1013) that the depositional environments of these rocks were affected by the Antler Orogeny along the west coast and the Acadian Orogeny along the east coast, and that effects of these orogenies can be traced into the intracratonic basins. They concluded that this tectonic framework resulted in the deposition of dark shale-light siltstone-dark shale sequences to occur with a general mirror-like symmetry on each side of the craton.

The Syringothyris brachiopod fauna of the siltstone members in the Bakken's depositional complex and in the Louisiana Limestone is also found in the light siltstone members in the eastern dark shale sequences. Gutschick and Moreman (1967, p. 1018, 1019) said that occurrences of this fauna in the eastern United States include the light colored, silty rocks of the New Albany Shale in Indiana and the Bedford Shale of Ohio; Swartz (1929) reported a similar fauna in the "middle gray shale member" of the Chattanooga Shale in Tennessee and Virginia. Gutschick and Moreman (1967, p. 1019) stated that faunas similar to the Syringothyris fauna occur near the systemic boundary in places throughout the world, including Great Britain, Germany, North Africa, China, and Japan.

#### Regional Correlation

The rocks and fossils of the Bakken's depositional complex have

been moderately well studied and have been found, in general, to comprise a widespread, vertical sequence of lithofacies and biofacies that "represent extensive, remarkably persistent strike deposition along the geosyncline across western United States into Canada" (Gutschick and Rodriguez, 1979, p. 42). Many of the beds in the Bakken's depositional complex are poorly fossiliferous but some contain abundant macrofossils; macrofossils from the upper part of the lower shale members and the lower part of the light siltstone members of the complex form widespread biosomes over much of the Western Interior.

Conodonts have proven to be a valuable tool in determining the biostratigraphy of the Bakken's depositional complex. Recent conodont studies (e. g., Sandberg and Klapper, 1967; Sandberg and Poole, 1977; Sandberg and Gutschick, 1979; Sandberg, et al., 1980) have resulted in detailed biostratigraphic control of most of the lithic units of the Bakken's depositional complex and have further located the position of the Devonian-Mississippian boundary in these rocks.

Most of the conodonts of the Bakken's depositional complex are from within the black shale members and thus these beds generally demonstrate the best biostratigraphic control of the complex. The conodonts in the light-colored clastic beds are "generally scarce and difficult to recover by conventional methods" (Sandberg and Gutschick, 1979, p. 127). They are locally abundant, however, and have been used to determine the biostratigraphic relations of most of the beds of the medial units of the tripartite sequence.

Figure 4 shows the conodont zonation scheme of the Bakken's depositional complex. Based on a new phylogenetic model of the conodont genus Palmatolepis, Ziegler and Sandberg (1984) have revised the upper part of

Figure 4. Correlation chart of the Bakken's depositional complex (see text). The timespans given are those of Sandberg, et al. (1983), and are based on conodont evolutionary rates; they noted (p. 695) that the currently accepted age for the Devonian-Mississippian boundary is about 360 million years before the present.

| System        |               | Stg./Ser. | MY from D-M boundary | CONODONT ZONE                   | Western Utah                       | Northern Utah  | Southwest Montana                   | Western Alberta                | Western North Dakota | Western South Dakota      |              |  |
|---------------|---------------|-----------|----------------------|---------------------------------|------------------------------------|--|-------------------------------------|--------------------------------|----------------------|---------------------------|--------------|--|
| MISSISSIPPIAN | KINDERHOOKIAN | +6        |                      | Lower <i>S. crenulata</i>       | Joanna Limestone (part)            | Lodgepole LS (part)  | Lodgepole LS (part)                 | Banff Fm (part)                | Lodgepole Fm (part)  | Pahasapa Limestone (part) |              |  |
|               |               | +4        |                      | <i>S. sandbergi</i>             | Upper Member                       | upper tongue, Cottonwood Canyon Member of the Lodgepole LS | upper tongue, Cottonwood Canyon Mbr | basal shale body               | upper shale          | upper member              |              |  |
|               |               | +3        | <i>S. duplicata</i>  | Upper                           |                                    | ?  | siltstone mbr                       | ?                              | ?                    |                           |              |  |
|               |               | +1.5      | <i>S. sulcata</i>    | Lower                           |                                    |  |                                     |                                |                      |                           |              |  |
| DEVONIAN      | FAMENNIAN     | -1        |                      | <i>Siphonodella praesulcata</i> |                                    | unit 7   | unit H                              | black shale body               | EXSHAW FORMATION     | middle member             |              |  |
|               |               |           |                      |                                 | unit 6                             | unit G   |                                     |                                |                      |                           |              |  |
|               |               |           |                      |                                 | unit 5                             | unit F   |                                     |                                |                      |                           |              |  |
|               |               |           |                      |                                 | unit 4                             | unit E   |                                     |                                |                      |                           |              |  |
|               |               | -2        |                      | <i>Bispathodus costatus</i>     |                                    |  | unit 3                              | unit D                         |                      |                           |              |  |
|               |               |           |                      |                                 |                                    |  |                                     | unit C                         |                      |                           |              |  |
|               |               |           |                      |                                 | Upper <i>Polygnathus styriacus</i> | black shale body (most of unit 1)                          | black shale body (units 1-3)        | black shale body (units A & B) |                      | lower shale               | lower member |  |
|               |               |           |                      |                                 |                                    |  |                                     |                                |                      |                           |              |  |
|               |               |           |                      |                                 | Middle <i>P. styriacus</i>         |  |                                     |                                |                      |                           |              |  |
|               |               |           |                      |                                 | Upper <i>Scaphignathus velifer</i> | Lower Member (part)  | Beirdneau Fm. (part)                | Trident Member (part)          | Palliser Fm (part)   | Three Forks Fm (part)     |              |  |

the standard Late Devonian conodont zonation scheme but their work has been received too late to be incorporated into this study.

Gutschick and Rodriguez 1979, p. 42) reported, "Everyplace where the lower black shale of the middle Pilot [Leatham Member] and equivalent strata has been observed from southeastern Nevada to western Montana and Alberta, the shale rests unconformably on the underlying rocks." Physical evidence of this regional unconformity include sandstone beds that typically occur at the base of the dark shales. sandstone beds were reported by Gutschick and Moreman 1967, p. 1015) to represent winnowed, current-sorted, lag deposits that commonly contain dark, shiny, and water-worn conodonts, phosphatic pellets, and fish plates, bones, and teeth. These basal sandstone beds are commonly less than two inches thick, but range up to over 10 feet thick in the Leatham Formation, where this sandstone bed of the dark shale is treated separate unit (Gutschick and Rodriguez, 1979, p. 44). Sandberg (1979, p. 9 reported that the this regional unconformity represents the timespan of two of the standard upper Devonian conodont zones (the Lower and Middle Polygnathus styriacus Biozones) in the western United States

The term "black shale" is actually somewhat of a misnomer in describing the rocks of the Upper Devonian-Lower Mississippian black shale lithofacies from around the craton, as rocks of this facies vary in color from black to dark gray or dark brown, depending on the amount of clay or silt present. Gutschick and Moreman 1967, p. 1015) reported that these dark shales are generally pyritic, noncalcareous, carbonaceous, and finely laminated with or without fissility. Ettensohn and Barron 1981, p. 346) said that the fissility of the dark shales is due to concentrations of silt- or clay-sized quartz grains into thin lamina-

tions and that the high carbon content of these shales represents colloidal-sized plant fragments of either marine or terrestrial origin. The lower black shale members in the Bakken's depositional complex, like the other Upper Devonian-Lower Mississippian black shales from around the craton, may also contain beds of black radiolarian chert, carbonate or phosphatic concretions, bentonite beds, and beds of dark greenish-gray mudstone; the thin but laterally extensive lag sandstones occur both at the base and within the shales (Gutschick and Rodriguez, 1979). The lag sandstones are often conglomeratic and cross-bedded, and also contain pyrite, chert, rock fragments, and occasional spores and trace fossils.

Gutschick and Moreman (1967, p. 1016) reported that the most common macrofossils in the black shale lithofacies are inarticulate brachiopods, such as Lingula and Orbiculoidea, disarticulated fish fragments, and plant remains, but that conodonts and spores are the most common fossils. Gutschick and Rodriguez (1979, p. 37) questionably assigned fragments of wood from these dark shales in the Western Interior to Calixylon and noted (p. 44) the presence of small radiolarians and sponge spicules in the chert beds of the lower black shales in the western United States. Macrofossils of the Devonian-Mississippian black shales from throughout the craton "usually reflect nektic, planktic, epiplanktic or necroplanktic life modes" (Ettensohn and Barron, 1981, p. 346). Benthic fossils are generally not present in the black shales of the Bakken's depositional complex (Gutschick and Rodriguez, 1967, p. Gutschick and Rodriguez, 1979, p. 44), and Ettensohn and Barron (1981, p. 346) reported that benthic macrofossils in the eastern black shales, such as brachiopods, gastropods, and pelecypods, "are especially rare,

but when they do occur, they always are found near the base of the sequence."

Conodonts that are diagnostic of the Late Devonian Upper Polygnathus styriacus Biozone have been reported from the lower black shale of the Bakken's depositional complex in the western United States and Canada, and thus these black shale bodies are considered to be of nearly the same age. As shown on the correlation chart (Figure 4), Macqueen and Sandberg (1970) believed that the upper portion of the Exshaw black shale may extend upward into the Mississippian; Sandberg and Poole (1977, p. 169) reported that the black shale members in the western United States may extend into the next younger conodont zone than the P. styriacus Biozone i. e., the Lower Bispathodus costatus Biozone of latest Devonian age) but, on the basis of physical and somewhat circumstantial faunal evidence, they assigned these black shales in the western United States solely to the Upper Polygnathus styriacus Biozone.

In contrast to the rest of the dark shales, the upper foot or so of the lower black shale members of the Bakken's depositional complex contains abundant benthic macrofossils and a different, younger, conodont fauna than the underlying dark shales. Gutschick and Rodriguez (1979 p. 44) wrote of this biosome: "This dark shale biofacies is very widespread along the geosynclinal margin. Single valves of the conchostracan Cyzicus (Lioestheria) sp. often cover the rich organic laminae in profusion, and occasionally articulated double-valves are common." These valves are small, thin, generally crushed, and lie flat on bedding planes of dark, carbonaceous shale. Gutschick and Sandberg (1970, p. 850) stated that the associated biota of this conchostracan zone, which extends from Nevada to Alberta,



. . . generally comprises inarticulate brachiopods, principally Lingula and Orbiculoidea, orthocone, nautiloid, and goniatite cephalopods, Tasmanites, and fish fragments, but locally includes abundant to rare ophiuroids, blastoids, and other pelmatozoans, articulate brachiopods, ostracods, conodonts, trilobites, horn corals, and sponge spicules.

Gutschick and Rodriguez 1979, p. 44) reported that this conchostracan bed contains a basal lag sandstone throughout its extent that is similar to, but much thinner than, the lag sandstone at the base of the lower black shale members. They stated (p. 44) that this basal lag sandstone of the conchostracan bed "is disconformable on the lower black shale marking a sharp change brought about by Antler orogenic unrest." Conodonts recovered from the black shales and basal sandstone of this biosome in the western United States are indicative of the Middle Bispathodus costatus Biozone of very late Devonian age. The disconformity at the base of the conchostracan bed is thus thought to represent the time of the Lower B. costatus Biozone; as shown on figure 4, rocks of this biozone in the Bakken's depositional complex appear to be represented by the lower tongue of the Cottonwood Canyon Member of the Madison Limestone and the lower member of the Englewood Formation (Sandberg and Klapper, 1967; Sandberg and Poole, 1977). Sandberg and Poole (1977, p. 172) have reported that conodont evidence indicates that the conchostracan bed in the western United States is essentially isochronous but Macqueen and Sandberg 1970, p. 52-53) reported that the one conodont collection of this biosome from the Exshaw Formation contains forms of undoubted Early Mississippian age; thus they suggested that this conchostracan bed is time-transgressive.

In some localities in the western United States, the lower black shale body in the Bakken's depositional complex is separated from the overlying light siltstone by thin, fossiliferous beds of shale or lime-

stone. A thin, greenish-gray shale up to several inches thick overlies much of the Sappington's black shale unit in southwestern Montana. The fossils of this bed are characterized by the clam Grammysia sp. and also include brachiopods, gastropods, and disarticulated pelmatozoan columnals. Conodonts from this bed are diagnostic of the Middle B. costatus Biozone and thus this bed is thought to be of nearly the same age as the underlying conchostracan bed of the Sappington Member. A two-foot-thick bed of bioclastic limestone that also contains a Middle B. costatus fauna overlies much of the black shale member of the Leatham Formation. Gutschick and Rodriguez 1979, p. 49) reported that this limestone contains a diverse but diminutive fauna of silicified or pyritized brachiopods, gastropods, goniatites, and other marine fossils. Based on morphologic features of these fossils, they stated (p. 49) that the minute size (maximum dimensions are less than 4 mm) is probably because they represent juvenile forms, rather than a depauperate fauna.

The light siltstone members in the Bakken's depositional complex generally make up a vertical sequence of several stratigraphic units that, like the conchostracan bed, form widespread biosomes over much of the Western Interior of the United States. In speaking of the upper of the Leatham Formation, Sandberg and Gutschick 1979, p. 127)

These units form a short segment of a remarkably uniform sequence of beds that was deposited in a narrow, originally continuous belt from northern Montana to southern Nevada. Lithogenetically, sequentially, and faunally identical strata are assigned to the Sappington Member of the Three Forks Formation in Montana and the middle member [Leatham Member] of the Pilot Shale in western Utah and eastern Nevada. This Sappington-Leatham-middle Pilot [Leatham Member] depositional subcomplex consists, in ascending order, of a basal lag sandstone; a conchostracan- and Tasmanites-bearing mudstone; an alga-brachiopod biostromal (oncolitic) silty limestone; and calcareous siltstone and sandstone interbedded locally with

silty mudstone, carbonaceous shale, and oolitic limestone.

Gutschick and Moreman 1967, p. 1015-1016) reported that the predominant lithologies of these silty beds are calcareous siltstone and silty limestone, with lesser amounts of shale and very fine- to fine-grained sandstone. The rocks are generally light-gray to medium-gray and greenish gray, and weather to a dark yellowish orange. Primary sedimentary structures were said to be common, and these consist largely of ripple marks, small scale cross-bedding, scour and channel fills, ball and pillow structures, and trace fossils. They reported (p. 1018) that the fossils of the siltstone units consist mostly of brachiopods that correlate with the Syringothyris fauna of the Louisiana Limestone and upper Saverton Shale of the upper Mississippi Valley

Based on its rocks and fossils, the siltstone member of the Sappington has been divided into four informal stratigraphic units in two independent studies. Gutschick, et al. 1962) designated these beds of the siltstone member of the Sappington as units E, F, G, and H and Sandberg 1965) designated these same beds as units 2, 3, 4, and 5. Units A through D of Gutschick, et al. 1962) represent, respectively, a dark, laminated shale interlayered with dark radiolarian chert, a dark, glossy, and nonfissile shale, the conchostracan bed, and the greenish gray fossiliferous bed; these four units were grouped together as unit 1 of the Sappington by Sandberg 1965). The siltstone member of the Leatham Formation was divided into three units by Sandberg and Gutschick (1969); units 5 and 6 of the Leatham Formation are equivalent to, respectively, the oncolitic E unit and the overlying F unit of the Sappington Member (Gutschick and Rodriguez, 1979, fig. 24). Unit 7 of the Leatham Formation is nonfossiliferous and is somewhat tentatively corre-

lated with the generally unfossiliferous units G and H of the Sappington. The Leatham Member of the Pilot Shale was described by Sandberg, et al. 1980, p. 72) to be "faunally, lithologically, and sequentially identical to the type Leatham Formation." They divided the Leatham Member into two stratigraphic units; unit 1 of the Leatham Member is equivalent to the lower black shale member of the Leatham Formation and unit 2 is equivalent to the conchostracan bed and overlying siltstone member of the Leatham Formation.

The lowest, oncolitic, unit of the siltstone members of the Sappington-Leatham-Leatham Member subcomplex is characterized by nodular oncolites and calcitic macrofossils mixed in matrix of silty, bioturbated limestone. This biosome was described by Gutschick and Rodriguez (1979, p. 46) as representing "one of the most persistent biofacies in this Late Devonian sequence." This deposit was thought to represent an algal bank because of the abundant oncolites and fossils "their vertical accumulation in the limestone layers outline a linear pattern parallel to the geosyncline margin and a low lenticular shape normal to it." This algal bank extends from western Utah to western Montana and typically ranges from about 10 to 15 feet thick. The oncolites average about one inch in diameter and range up to about three inches in diameter, but they become smaller and less common away the axis of the bank and are, in places, absent. No oncolites were found in the Leatham Member in eastern Nevada (Gutschick and Rodriguez 1979, p. 46)

These oncolites consist of calcareous, concentrically laminated, algal structures which commonly have a silicified fossil at their core. Gutschick and Rodriguez (1967 and 1979) etched oncolites from the Sap-

pington-Leatham-Leatham Member subcomplex in hydrochloric acid and obtained excellently preserved macrofossils, consisting mostly of Rhipidomella missouriensis and other brachiopods typical of the Syringothyris fauna of the Louisiana Limestone and the upper Saverton Shale. The calcitic fossils in the internodular matrix also consist of species of the Syringothyris fauna but are not as well preserved (Gutschick and Rodriguez, 1967). Besides brachiopods, other fossils reported from this oncolitic bank include pelecypods, gastropods, nautiloids, crinoids, trilobites, conchostracans, ostracodes, sponges, bryozoans, foraminiferids, conodonts, and trace fossils characterized by Scalarituba missourienis (Gutschick and Rodriguez, 1979, p. 46).

Unit E of the Sappington and unit 5 of the Leatham Formation contain conodonts of the Siphonodella praesulcata Biozone of latest Devonian age. Sandberg, et al. 1972, p. 189-190) reported that the S. praesulcata fauna is most commonly found in a silty lithofacies, such as in the oncolitic units of the Bakken's depositional complex, whereas shaly or carbonate rocks of equivalent age more commonly contain a Protonothodus kockeli fauna; it is this latter conodont fauna that is found in the Louisiana Limestone. The Syringothyris fauna in the Western Interior and the upper Mississippi Valley has been found to occur entirely within the S. praesulcata Biozone or its equivalent biofacies, and is thus thought to be solely of Latest Devonian age (Sandberg, et al., 1972, p. 185-188; Sandberg and Poole, 1977).

The rocks that overlie the oncolite unit throughout the Sappington-Leatham-Leatham Member subcomplex (unit F of the Sappington and its equivalents) appear similar to the oncolitic bed but contain fewer fossils and no oncolites. This biosome consists mostly of siltstone, silty

limestone, and silty shale, is up to about 30 feet thick, and contains a sparse, poorly preserved, Syringothyris fauna scattered throughout the matrix. Trace fossils are locally abundant and consist mostly of Scalarituba missouriensis, Cosmoraphe, and Bifungites. The top few feet of unit F are commonly occupied by a fossiliferous siltstone that contains abundant syringothyrids, spiriferids, and schellweinellids. Articulated crinoid calices have been found in unit F. A Siphonodella praesulcata conodont fauna has been recovered from this biosome in the Sappington Member and in the Leatham Formation.

The generally silty beds that overlie the Syringothyris-bearing unit F of the Sappington and its equivalents in the Sappington-Leatham-Leatham Member subcomplex are variably developed; these mostly unfossiliferous units are up to about 70 feet thick in the Sappington, about 25 in the Leatham Formation, and are absent in the Leatham Member.

difference accounts for a difference seen in the total thicknesses of these lithosomes, as the Sappington is up to about 130 feet thick, the Leatham Formation is up to about 95 feet thick, and the Leatham Member is only about 60 feet thick (Gutschick, et al., 1962; Sandberg, et al., 1980, p. 74).

Unit G of the Sappington consists predominately of medium to dark, greenish gray shale with lenticular channel-fill siltstones and intercalations of silty shale (Gutschick, et al., 1976, p. 104). This unit, up to about 25 feet thick, is the least extensive unit of the Sappington and grades laterally into unit H of the Sappington. Fossils other than trace fossils are rare in unit G and have been found mostly in a single channel-fill siltstone that contains articulated blastoids and species associated with the Syringothyris fauna (Gutschick and Rodriguez, 1967,

p. 601; Gutschick, et al., 1976, p. 104). The trace fossils, abundant near the top of the unit, are characterized by Bifungites and Diplocraterion (Rodriguez and Gutschick, 1970, p. 416). A Spelaeotriletes lepidophytus spore flora of latest Devonian age has been found within the top two feet of unit G; age-diagnostic conodonts have not been found in this unit.

Unit H of the Sappington, up to about 40 feet thick where it overlies unit G, consists of predominantly massive, calcareous siltstone with fewer sedimentary structures, such as ripple marks, crossbedding, and channel-fill scours, than seen in unit G (Rodriguez and Gutschick, 1970, p. 416). Trace fossils are common and diverse in this unit and are characterized by Scalarituba missouriensis, Zoophychos, and Bifungites (Rodriguez and Gutschick, 1970, p. 416). Other macrofossils in unit H are generally rare and poorly preserved but do occur in several thin, calcareous beds and are most common near the bottom and top of the unit (Rodriguez and Gutschick, 1967, p. 376). These fossils consist mostly of schellweinellid, camarotoechoid, and spiriferoid brachiopods (Gutschick and Rodriguez, 1967, p. 60 ; complete crinoids were found in one of the channel fills (Gutschick, et al., 1976, p. 104). No zonally significant fossils have been reported from unit H (Sandberg and Poole, 1977, p.

Unit 7 of the Leatham Formation is up to 25 feet thick and consists of black, carbonaceous mudstone in which no fossils have been found

Sandberg and Gutschick, 1979, p. 109 The lack of biostratigraphic control in this unit, as well as in unit H of the Sappington, has resulted in questionable Early Mississippian age assignments for these units, and thus the Sappington and Leatham Formation are considered to

be of Late Devonian and Early Mississippian ?) age (Sandberg and Poole, 1977, p. 172; Sandberg and Gutschick, 1979, p. 123), whereas the Leatham Member is considered to be of entirely Late Devonian age (Sandberg, et al., 1980, p. 74).

Gutschick and Rodriguez 1979, p. 53) tentatively correlated unit H of the Sappington and unit 7 of the Leatham Formation with the lower beds of the upper member of the Pilot Shale of earliest Mississippian age. The upper member of the Pilot Shale (hereafter referred to as the upper Pilot Shale) is a poorly fossiliferous, relatively thick sequence (about 200 feet thick) of siltstone and silty shale with occasional channel fills. This silty sequence separates the Syringothyris-bearing beds of the Leatham Member from the overlying, Lower Mississippian carbonates and thus appears to resemble the upper beds of the Sappington and Leatham Formation in lithology and stratigraphic position.

The worldwide Devonian-Mississippian boundary is defined as the contact between the Siphonodella praesulcata and overlying S. sulcata Biozones (Sandberg, 1979, p. 98). Rocks of the Bakken's depositional complex that contain a S. sulcata fauna have been reported from the base of the upper member of the Pilot Shale in Nevada by Sandberg, Poole, and Gutschick 1980, p. 75) and from the base of the upper tongue of the Cottonwood Canyon Member in one locality in Wyoming by Sandberg and Klapper (1967, p. B51-B52). Sandberg and Gutschick (1979, p. 127) reported that both the upper Pilot Shale and the Cottonwood Canyon Member contain the next youngest conodont zone, the S. duplicata Biozone. The Cottonwood Canyon Member and the Englewood Formation also contain the next two younger conodont zones which, in ascending order, are the S. sandbergi and the Lower S. crenulata Biozones (Sandberg and Klapper,



1967; Sandberg and Gutschick, 1979)

Macrofossils are rare and poorly preserved in the early Mississippian rocks of the Bakken's depositional complex, and little work has been published on them. Sandberg and Klapper (1967, p. B27) reported that spores, conodonts, fish fragments, linguloid brachiopods, and Zoophycos-like trace fossils are present throughout the Cottonwood Canyon Member and that fenestrate bryozoans, pelmatozoan columnals, and corals assigned to the genus Syringopora occur locally. **Macrofossils reported** from the Englewood in South Dakota include the brachiopods Pararhynchus and Productus s. l. by Klapper and Furnish (1962, p. 2072) and poorly preserved schuchertellids, productids, Leptaena sp., and "many crinoid stems" by Kume 1963, p. 19).

Biostratigraphic correlation of the Bakken's nearest correlative, the Exshaw Formation, was reported by Macqueen and Sandberg (1970, p. 47 to be "difficult because of the scarcity and generally poor preservation of both megafossils and microfossils at the type locality and in the Front Ranges." As mentioned, the Devonian-Mississippian boundary in western Canada is thought by Macqueen and Sandberg 1970, p. 53) to probably occur within the black shale member of the Exshaw, as conodonts of the late Devonian Polygnathus styriacus Biozone have been recovered from the Exshaw's basal lag sandstone and Kinderhookian conodonts have been recovered from near the top of this member. Other paleontologic evidence suggesting that the lower part of the Exshaw black shale is of late Devonian age is the presence of the supposed pelagic algal form Foerstia sp. in this interval of the Exshaw (Cross, 1982). Foerstia sp. is a common but inconspicuous fossil at a particular stratigraphic horizon in the eastern black shales and is considered to be a significant

time-stratigraphic marker of Late Devonian age in those rocks. Foerstia sp. has always been found between one-seventh to two-fifths of the way up in the black shale sequence, "regardless of the total thickness of those beds" (Mathews, 1983, p. 329). Conkin, et al. (1980, p. 3) stated that this specific positioning of the Foerstia sp. Biozone, in conjunction with the similar specific positioning of paracontinuous, conodont-bearing lag sandstones in the eastern black shales, demonstrate that these beds, "and thus these shale sequences themselves, are not time transgressive."

Macqueen and Sandberg (1970, p. 40) reported that the lithology of the Exshaw siltstone member is indistinguishable from the lithology of unit H of the Sappington. They described the general lithology of the Exshaw siltstone member, up to about 130 feet thick, as a "very calcareous siltstone, grading at some levels to very silty limestone." They speculated (p. 54) that the northward disappearance of the fossiliferous units of the Sappington siltstone member "might be explained by a facies change from siltstone to black shale, b) depositional wedge-out or c) truncation resulting from an unrecognized unconformity within the black shale unit."

The macrofossils of the Exshaw siltstone member consist largely of productoids, camarotoechoids, and species of Spirifer. Harker and McLaren (1958, p. 251) wrote that "none of the fossils are specifically identifiable and may be referred to genera only with hesitation. The forms present, however, bear some resemblance to specimens of the Louisiana Limestone." This fauna was designated as the "Spirifer marionensis zone" by Harker and Raasch (1958, p. 228), who named it after a characteristic species of the Louisiana Limestone. They

reported that the S. marionensis Biozone "appears to range through at least 100, and possibly several hundred feet of lower Banff strata . . .

Because of later conodont evidence suggesting that the Louisiana Limestone is of latest Devonian age and the Banff Formation is no older than early Kinderhookian, Green 1962, p. 296) questioned the presence of S. marionensis in the Banff Formation, and thus used the term "(?) S. marionensis Biozone" for describing this assemblage zone in Canada.

Gutschick and Rodriguez 1967, p. 604) correlated the brachiopods from unit E of the Sappington with the S. marionensis fauna of "the lower Banff in Alberta." Macqueen and Sandberg 1970, p. 39-40) subsequently revised the Exshaw's type section to include the basal 90 feet or so of the overlying Banff Formation because they could see no difference between the lower, silty beds of the Banff and the siltstone beds of the Exshaw Formation.

According to Green 1962, p. 296, 301), the S. marionensis Biozone occurs in the "lower" and "middle" members of the Banff Formation in Alberta and thus the top of this biozone occurs stratigraphically about 400 feet above the top of the Exshaw Formation. Brindle 1960, p. 18) correlated the S. marionensis fauna with the "Souris Valley beds" of the Lodgepole Formation (Banff Formation) in southeastern Saskatchewan, where these beds overlie the Bakken Formation. Brindle 1960, p. 17) reported that the S. marionensis fauna extends upward into the bottom one-third of the "Tilston beds", which overlie the "Souris Valley beds" in Saskatchewan and are of Late Kinderhookian age.

Macqueen and Sandberg 1970, p. 47 reported that two small collections of conodonts from the Exshaw siltstone member, one from within the basal three feet of the member, indicated an early, but not earliest,

Kinderhookian age for this lithosome; such an age assignment thus supported their early Mississippian age assignment for the underlying conchostracan bed of the Exshaw

Macrofossils of the Bakken Formation have generally not been adequately studied for their correlation with the various stratigraphic units of the Bakken's depositional complex; equivalents of the fossiliferous biosomes of the Sappington have not been reported from the Bakken. Brindle 1960, p. 16) Christopher (1961, p. 19, 20), and Gutschick and Moreman 1967, fig. correlated the brachiopod fauna of the Bakken siltstone in Saskatchewan (as described by Brindle, 1960) with the Syringothyris fauna of the Sappington and the Louisiana Limestone largely on the basis of the presence of Rhipidomella missouriensis in cores from Saskatchewan. Gutschick and Moreman 1967, fig. ) indicated that the fossils of the Bakken in North Dakota consisted largely of unidentified brachiopods and conodonts, and thus their correlation of the Bakken in North Dakota was based largely on physical evidence.

Biostratigraphic work on the Bakken Formation in the United States consists essentially of the conodont study by Hayes (1984, 1985), who found conodonts suggestive of the Upper Polygnathus styriacus Biozone throughout the lower shale and conodonts that suggest an early, but not earliest, Kinderhookian age for the upper Bakken shale. He reported that the upper few feet of the upper Bakken shale in North Dakota contains conodonts diagnostic of the Lower Siphonodella crenulata Biozone. An age no earlier than this was also suggested for the dark shale in north-central Montana by Sandberg and Klapper (1967, p. B38), who found conodonts of the Lower S. crenulata Biozone at the base of the Lodgepole Formation where it overlies this shale in outcrop in the Little Rocky

Mountains. Hayes (1984, 1985) did not find any identifiable conodonts in the middle member but indicated (p. 80) that the stratigraphic interval between the Bakken black shale members represents a relatively long period of time.

Macqueen and Sandberg (1970, p. 52) reported that the micropaleontological evidence for the correlation of the Bakken in Canada is limited to two cores from southeastern Alberta; one of these cores contained conodonts in the lower shale member that included two species associated with the Late Devonian Upper P. styriacus fauna and the other core contained palynomorphs in the middle member that have been identified as belonging to the Spelaetriletes lepidophytus spore assemblage, similar to that found in unit G of the Sappington. Aside from this, age determinations of the Bakken are based largely on its physical correlation with the biostratigraphically controlled rocks of its depositional complex.

## MATERIALS AND METHODS

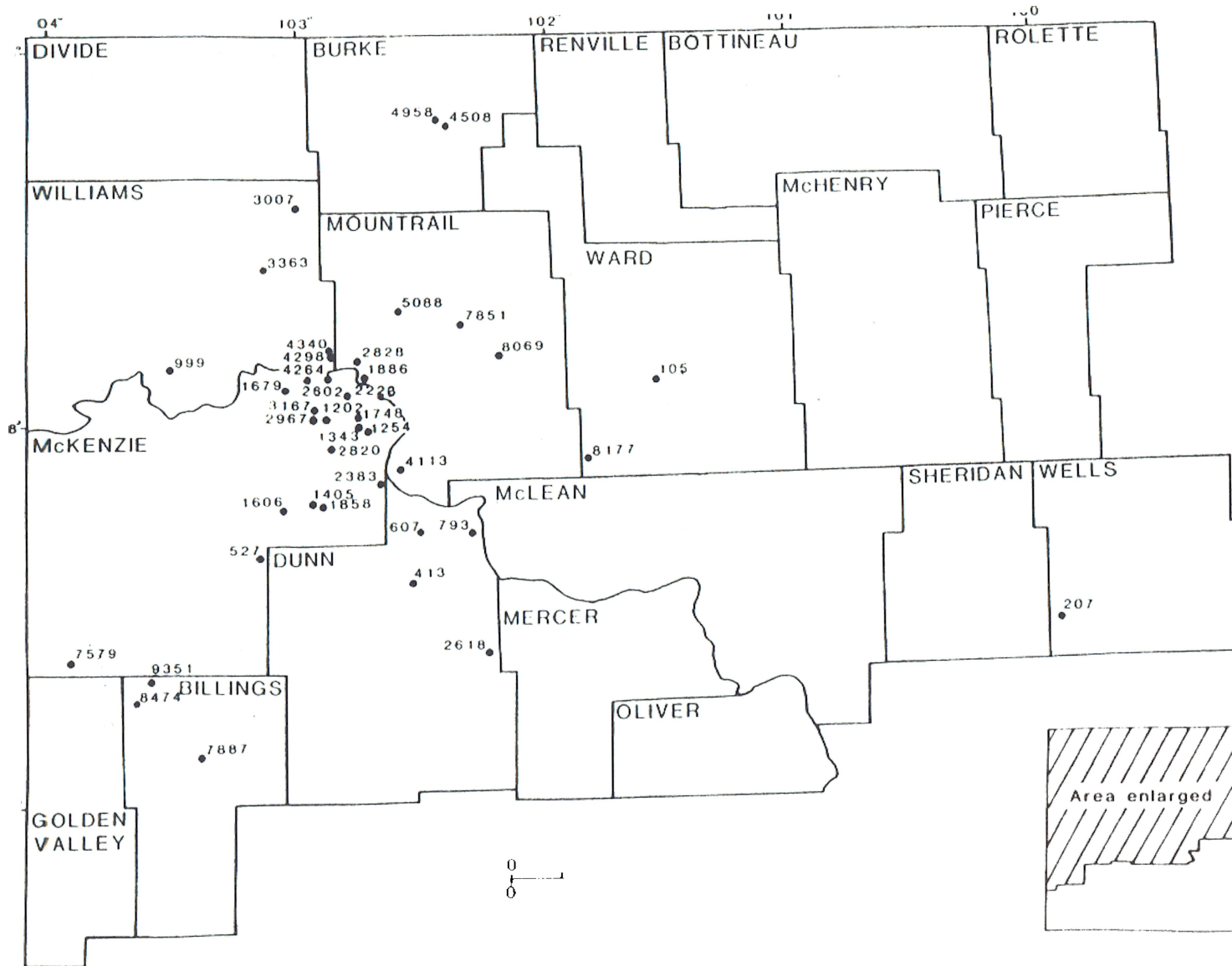
### Collecting Techniques

Forty cores were found that contain some interval of the Bakken Formation, and of these, 26 yielded fossils. The cores that did not yield fossils are mostly in poor condition and most of them represent less than ten feet of the generally unfossiliferous lower shale member. Only three cores (not including a few cores from near the margins of the formation) were found that contain the complete Bakken section. The lower shale member was found in 33 of the cores, the middle member was found in 24 cores, and the usually thin, upper shale was well represented in 16 cores.

The locations of the wells from which core was taken are shown on Figure 5. Almost all of the cores are from wells in the central part of the Williston Basin where formations tend to reach their maximum development. Four cores are from near the southwestern margin of the Bakken and two are from near the eastern limit of the formation. In all, nearly 1500 feet of Bakken core was examined.

The physical condition of the cores was found to range from poor to excellent. The core is generally broken, averaging about five to ten pieces in a three-foot core box, and this provided numerous bedding planes for examination for fossils. Most of the large-sized cores (3 1/2 to 4 1/2 inches in diameter and many of the smaller cores (2 or 1/2 inches in diameter were found to have had anywhere from one-fifth to one-half of the diameter slabbed and removed for previous studies. This technique greatly enhances the opportunity for observation of lithologic features of the core but, as it reduces the fossil content of the core, no slabbing was done on the few remaining unslabbed cores

Figure 5. Location of wells used in this study. Well numbers are those of the North Dakota Geological Survey. Well names and localities are given in Appendix 1; descriptions of cores in which fossils were collected are given in Appendix 2.





The lithology of all cores was described, and all fossils were collected or were noted in the core description sheets at the depth at which they occur. The fossils consist mostly of calcitic brachiopods from the middle member but also include a number of other forms, such as mollusks, the conchostracan Cyzicus, trace fossils, plants, and fish fragments; many of these fossils were found in the black shale members of the formation. The NDGS well number, depth, and orientation (indicated by an arrow pointing up the hole) was recorded on the side of each fossil-bearing core piece removed. The core pieces removed for study were replaced with crushed paper to maintain the correct depths for the other pieces in the core box.

During the description of the cores, several stratigraphic intervals within the Bakken were found to be particularly fossiliferous; these intervals were re-examined for fossils by splitting the cores of these intervals down to pieces about 3 inches thick. Splitting the hard, massive rocks of the middle member generally required the use of a hydraulic rock splitter.

#### Laboratory Techniques

Approximately 250 core pieces that contain a combined total of considerably more than 500 fossils were collected and taken to the paleontology laboratory in Leonard Hall for further work. The fossils were excavated from encasing matrix by using a hammer and a set of chisels and more delicate work was done by using a steel probe and a camel hair brush under a stereoscopic binocular microscope with magnifications from 10X to 80X. Some fossils were broken during excavation and were glued back together with DuPont "Duco cement". The more delicate fossils were given a coating of a dilute solution of gum tragacanth. Latex casts and

molds were made from some of the fossils to aid in their identification and illustration.

The NDGS well-numbering system assigns a non-repeatable number to all oil and gas wells drilled in North Dakota, and this system was used as a basis for encoding the fossils. Specimen numbering was done by having the specimen with the lowest stratigraphic horizon in a particular well be given a specimen number of 1, and have this increase in increments of 1 for each fossil successively higher up in the core. The code number of a specimen consists of its NDGS well number followed by a decimal point, followed by its specimen number. For example, the fossil collected from the deepest horizon in NDGS Well No. 607 is 607.1, the next fossil higher up is 607.2, and so on.


This system provided the flexibility for easily accommodating any additional fossils added to the collection. This became necessary, as the fossiliferous zones were re-examined and collected from after the initial encoding of the fossils. Code numbers of these added fossils have an extra decimal number that starts with a .2 and increases in increments of .2, although this system varied according to need. For example, if two specimens were subsequently collected from NDGS Well No. 607 from between the specimens 607.1 and 607.2, the code numbers of these additional specimens would be 607.1.2 and 607.1.4.

Specimens subsequently selected for illustration (the chirohypotypes) were cataloged into the paleontology collection of the University of North Dakota (indicated herein by a four-digit number preceded by UND and followed by a period). Generally, one catalog number was assigned to each bedding plane illustrated, regardless of the number of fossils on that bedding plane; in a few cases, specimens of different taxa on

the same bedding plane were given individual catalog numbers.

Where the fossiliferous zones in the middle member are calcareous core chips were taken for dissolving in acetic or hydrochloric acid baths. Although the original calcite in many of the fossils has been partly replaced with silica and pyrite or other sulfides, efforts to free them by using acid baths proved largely disappointing; enough calcite would remain in the specimen so that the acid would destroy the fossil while dissolving the matrix. The calcite of small fossils was frequently completely replaced by silica or pyrite, however, and a number of minute fossils, mostly juvenile brachiopods and gastropods, were collected from the residues of dissolved core pieces from near the base of the middle member. Dissolved core pieces that yielded fossils were given code numbers as previously described; individual fossils from these core pieces were assigned lower case letters starting with the letter "a" after the code number. For example, if 607.1 was dissolved and two fossils were collected from the residues, they would be encoded as 607.1a and 607.1b.

Over 200 thin sections of the Bakken Formation, left from previous studies, were incorporated into this study. Ten additional thin sections were made to aid study of various paleontologic and sedimentologic features of the formation. The thin sections cover nearly all of the different lithologies of the formation and a number show cross sections of fossils. The thin sections were examined under a cross-polarizing petrographic binocular microscope at 28X to 400X. They were compared with the core descriptions to check the lithologic descriptions previously made. The lithologies of the core descriptions and those determined from thin sections generally agreed quite well.



Macrofossils were photographed with a 35mm SLR Nikon F3HP camera with a 55 mm, f2.8 Micro-Nikkor lens. A Nikon PB-6 bellows focusing attachment was used for smaller specimens. Most fossils were coated with a sublimate of ammonium chloride just prior to photography, although some were best left untreated. Lighting consisted of a main light source from the upper left and a secondary light source from the lower right. Kodak Panatomic-X, Plus-X, and Tri-X films were used, and the prints were made on Kodak F-2 or F-3 Kodabrome II RC paper. Final plates were made by Randy Haight at the Division of Biomedical Communications, University of North Dakota.

## RESULTS

The more than 500 macrofossils collected from the Bakken Formation were found to represent more than 50 taxa, 25 of which are brachiopods identified at least to genus. Nonbrachiopod fossils include a hylothyrid, a conulariid, a syringoporid coral, gastropods, cephalopods, cypods, a trilobite, ostracods, the conchostracan Cyzicus (Lioestheria) a eumalacostracan, fish fragments, plants, and trace fossils. The stratigraphic occurrences of the taxa are shown in a distribution chart as Figure 6. The depth and well from which each fossil was collected is shown in the core description sheets of Appendix 2. Appendix 3 is a list of the fossils found, arranged by code number; Appendix 4 is the code numbers of the fossils arranged by taxa.

Almost all of the fossils of the Bakken Formation were found to occur within five stratigraphic intervals. Two of these fossiliferous intervals are in the lower shale and the other three are in the middle member. These intervals range in thickness from a few inches to nearly 30 feet and the fossils range from rare to abundant in them. Most of the taxa are restricted to one or a few of these intervals, and thus each interval appears to contain its own assemblage.

The lithology of the two fossiliferous intervals in the lower member consist of dark-gray to black shales (N3-N1) that are indistinguishable from the rest of the member. The fossils of both shale members of the Bakken are preserved as flattened molds of the interior or less commonly, as carbonaceous impressions. Some have partly been replaced by pyrite or, less commonly, by other sulfides. Details on the preservation of each of the Bakken fossils are given with the systematic descriptions.

Figure 6. Faunal occurrence chart. The chart includes all macrofossils of the Bakken Formation from western North Dakota except for unidentified brachiopods. Generally, each specimen is represented by filling in the column for that taxon a width of about two-thirds of one millimeter; a filled column represents ten or more specimens. The abundance shown for *Foerstia* sp. and *Cosmoraphe* sp. is based on the number of occurrences noted in the cores; both are small forms that, where found, occur in abundance. The proportions of the rock units are based on those of the type section. The stratigraphic ranges of the taxa cover the lower and upper shale members in ten percent increments of those members and the ranges in units 1 and 2 (see text) are in twenty-five percent increments of those units. Ranges in unit 3 are not subdivided.

[illegible]



The stratigraphically lowest interval of the Bakken occurs within about the bottom seven feet of the lower shale member. This is the least fossiliferous of these fossiliferous intervals, as macrofossils were typically rare or, more commonly, absent in this interval. Fossils were found in six of the 18 cores (NDGS Well Nos. 527, 1679, 2226, and 2383 in McKenzie County, 607 in Dunn County, and 5088 in Mountrail County) that contain this interval, however, and were common in three of them. They were particularly abundant in this interval in one core (NDGS Well No. 2383) from McKenzie County, and this core contains most of the taxa of this assemblage. Many of the taxa were found in several of the cores, however, thus suggesting that they are all part of the same assemblage

The fossils of this lowest zone are characterized by benthic forms and consist of a hylothyrid, Lingula sp. 2, Barroisella sp., a rhynchonellid (Rugaltarostrum montanensis), fragments of small, costate rhynchonellids, a bellerophonid, (Phragmosphaera sp.), a low-spined gastropod assigned to Straparollus (Straparollus) sp. 2, a straight cephalopod, a coiled cephalopod, what appears to be several species of pelecypods, conchostracan valves assigned to Cyzicus (Lioestheria) sp., fish scales, one occurrence of a Spirophyton-like trace fossil, and minute spinules of unknown affinity. Also found in this interval were ostracods, conodonts, and palynomorphs. Conchostracan valves in this interval were particularly abundant in NDGS Well No. 5088 in Mountrail County, where they nearly cover some of the bedding planes. Lingulaceans are abundant in places and are concentrated in a bed of dark gray shale about 2 mm thick in NDGS Well No. 2383 from McKenzie County. As shown on the distribution chart, these taxa range from rare to abundant,



with conchostracans being the most common fossils of this zone.

The upper fossiliferous zone of the lower shale member occurs within the top six inches of the shale and, like this stratigraphic interval in the Western Interior, contains abundant valves of the conchostracan C. (Lioestheria) sp.. The valves lie flat on bedding planes are crushed, many are fragmental, and almost all are disarticulated; they have a large range in size and many are very small, with maximum dimensions of less than 5 mm. Conchostracans were found near the top of the lower shale member in eight of the 14 cores that contain at least some part of this interval. This thin bed appears to mark a persistent biosome in and near the area that Webster (1982, p. 20) and Hester and Schmoker (1985, map C) mapped as being the depocenter of the lower black shale but, interestingly, was not found in any core from outside of this area. The lateral extent of the conchostracan bed is shown on Figure 10 in the chapter on depositional environments. The fauna of this biosome in the Bakken Formation appears to be much less diverse than is the conchostracan bed in the Bakken correlatives or the fauna from near the base of the lower shale; the only other macrofossil found within the top few inches of the lower shale member is one carbonaceous impression of a shrimp-like organism. The ubiquitous conodonts and palynomorphs of the black shales were also present in the Bakken conchostracan bed.

Outside of these two fossiliferous zones, macrofossils were rarely found in the lower shale member; those found consist of one valve of Lingula sp. 3, one small but complete orthoconic cephalopod, scattered fish scales and teeth, Foerstia, sp. and two possible plant stems. Numerous thalli of Foerstia sp. were found on bedding planes over a three-foot-thick interval in one well from near the center of the basin

(NDGS Well No. 4340, Williams County). This interval occurs within the bottom 20 to 30 percent of the lower shale member in that core and thus Foerstia sp. was found to occur in the Bakken at a similar stratigraphic level as everywhere else it is found. Large ostracod-like valves of uncertain affinity, up to about 6 mm long, were found scattered throughout the lower Bakken shale (except in the conchostracan bed) and were

common in NDGS Well No. 5088 in Mountrail County. These valves lie flat on bedding planes and most are articulated along the hingeline or have slipped slightly past each other. Conodonts were uncommonly concentrated into thin (about one centimeter thick) beds of dark, very pyritic shale or equally thin beds of siltstone or fine-grained sandstone rarely interbedded in the dark shales. These thin siltstones or sandstones were discussed by Hayes (1984) and are currently being studied by Timothy P. Huber

Fossils from the middle member of the Bakken Formation consist mostly of calcitic brachiopods that are fairly common but were found almost entirely within about the lower 40 percent of the member (up to about 30 feet thick) and within the top five to eight feet of the mem-

This occurrence of the fossils closely coincides with a tripartite succession seen in the lithology of the middle member. Based on the rocks and fossils, the Bakken middle member of North Dakota is thus easily divisible into three stratigraphic units that are here informally designated as units 1, 2, and 3 for the lower, middle, and upper parts of the member, respectively. Units 1 and 3 consist mostly of massive fossiliferous siltstone and unit 2 consists of predominantly thin unfossiliferous, and well-sorted beds of shale, siltstone, or fine-grained sandstone. The shales of unit 2 are typically dark-gray and

siliceous whereas the sandstones are mostly light-gray and have calcareous cement. The thickness and stratigraphic relations of the units of the middle member are shown in cross section on Figure 7.

Fossils from the middle member are fairly well preserved, although most shells are slightly crushed and decorticated, and few internal structures were found. The valves did not break out of the matrix easily, and were mostly studied with parts of the shell embedded in the matrix. Most specimens, however, had enough distinguishing features to make generic and many specific identifications possible.

Unit 1 of the middle member is about 8 to 32 feet thick, depending on the overall thickness of the member, and consists largely of light- to dark-gray (N2 to N9), brownish-gray (5YR4/1), or light to medium greenish gray (5Y4/1 to 5Y6/1), calcareous, fossiliferous, and pyritic siltstone that, in places, grades into a silty limestone. Bedding is rare and is generally comprised of distorted or disrupted beds of sandstone up to several inches thick. Further lithologic descriptions of the Bakken cores are provided in Appendix 2.

Macrofossils are generally common in unit and form the third fossiliferous interval of the Bakken Formation. The assemblage of this interval consists mostly of calcitic brachiopods and closely resembles the Syringothyris fauna of the Sappington Member of the Three Forks Formation and the Louisiana Limestone. The fossils are numerically dominated by Rhipidomella missouriensis and trace fossils characterized by Scalarituba missouriensis. The calcitic fossils are fairly common in the bottom one-half of the unit (typically about 5 to 10 feet thick) but are rare in its upper one-half, and the trace fossils occur in almost direct inverse proportion to this; that is, they are rare in the bottom

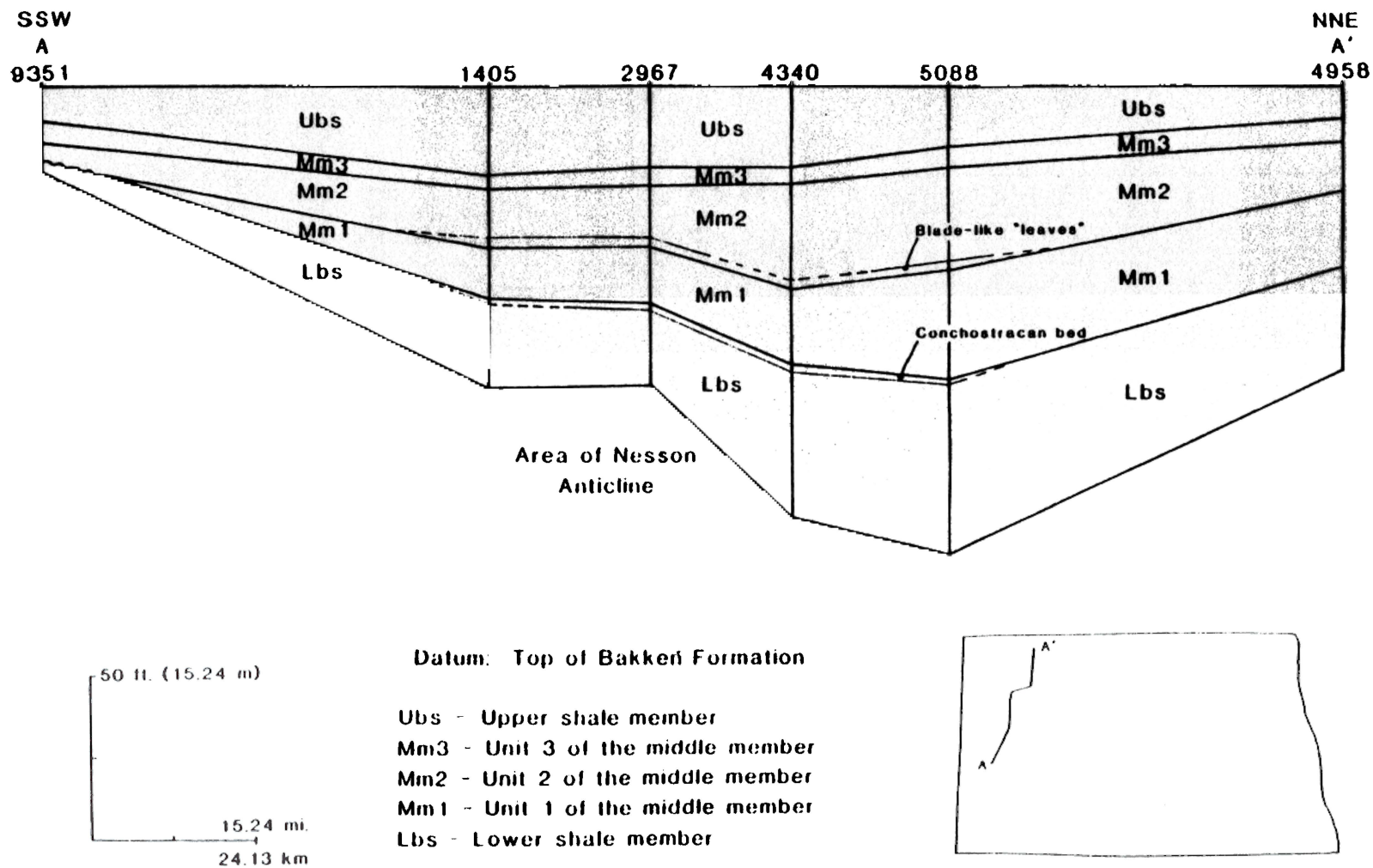


Figure 7. Generalized cross section of the Bakken Formation. Core descriptions of the wells depicted are given in Appendix 2.

one-half of the unit and are fairly common in the upper one-half.

Besides R. missouriensis, the brachiopods found in unit 1 consist of Lingula sp. 4, Orbiculoidea limata, Schellweinella inflata, Schuchertella lens, one possible immature chonetid, Orbinaria pyxidata, Rhytiophora arcuata, fragments of costate rhynchonellids, Tylothyris clarksvillensis, and Syringothyris hannibalensis. Nonbrachiopod fossils (other than the trace fossils) are relatively rare and were found solely in the bottom few feet of the member; these fossils consist of minute gastropods, assigned to Straparollus (Straparollus) sp. 1, Loxonema cf L. missouriensis, an orthoconic cephalopod (similar to the one in the lower shale), a juvenile goniatite, graptolite and prothyrid pelecypods, ostracods, one unflattened valve of C. (Lioestheria) sp., fragments of pelmatozoan columns, and one possible plant stem. Juvenile brachiopods were collected along with the minute gastropods and the juvenile goniatite from the residues of hydrochloric acid baths. Small twig-like fossils were also found throughout unit 1. The trace fossils of unit consist of Scalarituba missouriensis in close association with a small, inconspicuous Cosmoraphe sp., and rarely found, simple, isolated tubes assigned to Planolites. Microfossils found in unit 1 consist of two fragments of arenaceous foraminiferids and one disarticulated ostracod valve.

Unit 2 is from about 10 to 35 feet thick, largely unfossiliferous, and makes up about one-half of the thickness of the middle member of the Bakken. This unit consists of mostly thin, alternating beds of dark-gray (N2-N3), siliceous shale, medium gray (N4-N6), slightly calcareous siltstone, and light-gray (N7-N9), calcareous, and fine-grained sandstone. The beds of unit 2 display numerous, well-defined, primary bed-

structures, such as cross bedding, current bedding, scour surfaces cut-and-fill structures, and ripple marks; these thin beds are frequently truncated. One unusually thick bed of light-gray (N7-N9), fine- to coarse-grained, and very calcareous sandstone or sandy limestone, up to about 10 feet thick, was found in the upper half of unit 2 in a num-

of the cores. This sandy bed typically contains many primary bedding structures, locally grades into an oolitic limestone, and is easily detectable on well logs. The contact between unit 1 and unit 2 is poorly defined; it was usually picked at the lowest occurrence of well-defined bedding, although, rarely, the bottom few feet of the well-defined beds contain a few fossils of the unit 1 fauna; in these cores the top of unit 1 was picked at the uppermost occurrence of the fossils.

Although fossils were generally absent in unit 2, a thin (up to about four feet thick) fossiliferous interval (the fourth such interval in the Bakken) occurs at or near the base of the unit. The fossils of

interval consist of carbonaceous impressions of blade-like "leaves" lie flat on thin, well-defined, bedding planes. The plants are generally poorly preserved, inconspicuous, and were found on just one bedding plane in some cores. Plants in this interval were found in seven cores (NDGS Well Nos. 413 in Dunn County, 607, 1202, 1405, 2967 and 3167 in McKenzie County, and 5088 in Mountrail County of the 15 cores found that contain this interval. These plants seem to form a laterally persistent biosome in much the same area as does the conchost-racan bed; the plants appear to be confined to the depocenter of the middle member, which largely overlaps that of the lower black shale (Webster, 1982, p. 21; Hester and Schmoker, 1985, map D).

Other fossils found in unit 2 consist of a syringoporid coral and

Spirifer sp. from one core piece from near the bottom of the unit (collected from an acid bath residue by Hayes, 1984), four stem-like fossils from near the top of the unit, and two occurrences of the trace fossil Chondrites. Three of the stem-like fossils occur on the same bedding plane in NDGS Well No. 785 in Mountrail County

Unit 3, about 3 to 10 feet thick, was found to consist predominantly of a massive, medium-gray (N4-N6), slightly calcareous, and fossiliferous siltstone that appears similar to the lithology of unit 1 but contains more well-defined beds; these beds are most common in the bottom one-half of the unit and are similar to the thin beds of unit 2 but are fossiliferous. The basal contact of unit 3 appears to be transitional with the thin beds of unit 2; and, in some cores, well-defined bedding extends upward through most of unit 3 (i. e., to near the top of the middle member. In these cores, the contact between units 2 and 3 is picked just below the lowest occurrence of fossils, which was always within the top eight feet of the middle member.

Macrofossils are generally common in unit 3 and some beds contain the richest concentrations of brachiopods to be found in the Bakken; this is the fifth fossiliferous interval of the Bakken Formation. The fossils consist almost entirely of brachiopods and appear to represent a different assemblage than do the fossils of unit 1. The faunal differences between these two units can be seen in detail on the distribution chart (Figure 6). The fauna of unit 3 differs rather conspicuously from unit 1 by containing, often in abundance, Chonetes gregarius, C. ornatus, Syringothyris halli, Spirifer greenockensis, and Spirifer sp. and by lacking some of the characteristic species of unit , such as Schellweinella inflata, Schuchertella lens, Tylothyris clarksvillensis, and

Syringothyris hannibalensis. Also, rhynchonellids are much more common in unit 3 than in unit 1 and Rhipidomella missouriensis is much rarer in 3 than in unit 1. Other brachiopods that occur in both units 1 and 3 are Lingula sp. 4, Orbiculoidea limata, Orbinaria pyxidata, and Rhytiophora arcuatus. Other brachiopods from unit 3 are Rugosochonetes sp., Composita spp. 1 and 2, and Torynifer sp.. The nonbrachiopod fauna of unit 3 is less diverse than that of unit 1, as it consists of one pelecypod valve, a minute pygidium of Brachymetopus (Brachymetopus) sp., one possible pleuron of a trilobite, a few possible arthropod fragments, and rare, disarticulated pelmatozoan columnals; no trace fossils were found in unit 3. Microfossils found in unit 3 consist of two fragments of arenaceous foraminiferids and 5 disarticulated ostracod valves.

Like the upper shale member of the Bakken Formation, unit 3 of the middle member appears to have a poorly defined depocenter and, aside from regional trends, both of these units seem to thicken and thin independently of the rest of the formation. This structural relationship is apparent in the cross-section of the formation (Figure 7) where, for example, it can be seen that the lower Bakken shale and units 1 and 2 of the middle member thin out over the Nesson Anticline, whereas the thickness of unit 3 and the upper Bakken shale do not appear to be affected by it.

The upper shale member of the Bakken Formation is about 10 to 25 feet thick in the cores and consists of sparsely fossiliferous, dark- to black (N3-N1), and thinly bedded shale similar to that of the lower shale member. Although macrofossils were found to be relatively common over a short interval in a few of the cores (especially in the upper one-half of the member), no laterally persistent fossiliferous



intervals were found in the upper shale member. One core piece from about five feet below the top of the member in NDGS Well No. 607 (Dunn County) contains the conchostracan C. (Lioestheria), three small brachial valves of Orbiculoidea limata, the basal view of an indeterminate gastropod, and several very small and disarticulated pelmatozoan columnals. An interval a few inches thick from within the top foot of the member in NDGS Well No. 5088 (Mountrail County) contains several valves of Lingula sp. 1, C. (Lioestheria) sp., a few minute chonetids, and one valve of a juvenile productid. Other macrofossils of the upper shale member consist of rare and scattered fish remains, one woody plant fragment or reed collected by Webster (1984), and the conulariid fragment collected by Kume (1963). In addition, one bedding plane at the base of the member contains two valves of Rhipidomella missouriensis, but there is evidence that these valves were reworked from the middle member as is explained in the section on systematic paleontology. Microfossils found in the upper black shale consist of conodonts, palynomorphs, a few ostracod valves, and one relatively large ostracod-like organism similar to those found in the lower shale member.

## DISCUSSION

### Intrabasinal Correlation

The lithology of the cores in this study has been described in some detail by Kume (1961), Webster (1982), and Hayes (1984) and the cores appear lithologically similar to Bakken cores from Saskatchewan and Manitoba that have been described in varying detail by Fuller (1956), MacDonald (1956), McCabe (1959), and Christopher (1961 and 1962).

Christopher (1961) is the only previous worker to have proposed stratigraphic subdivisions for the middle member, and the units proposed here for the middle member appear to be just a slightly different way of subdividing comparable rocks. Unit 1 appears to correspond exactly to his A bed, unit 2 is the equivalent of his B<sub>1</sub>, B<sub>2</sub>, and B<sub>3</sub> beds, and unit 3 equals his B<sub>4</sub> bed. His subdivision of unit 2 into his B<sub>1</sub>, B<sub>2</sub>, and B<sub>3</sub> beds is based on the presence of a thick bed (up to about 25 feet thick) of calcareous sandstone or sandy limestone with many primary bedding structures, which he designated as the B<sub>2</sub> bed and used to separate his B<sub>1</sub> and B<sub>3</sub> beds. His B<sub>2</sub> bed appears to be similar to the relatively thick bed of sandstone or sandy limestone noted in the cores of this study, and his B<sub>1</sub> and B<sub>3</sub> beds seem similar to the thin-bedded clastics of unit 2. His system was not used here because the thick sandy bed (his B<sub>2</sub> unit) is commonly absent in the cores of this study; thus, in many areas of North Dakota, there is no practical way of distinguishing his B<sub>1</sub> bed from his B<sub>3</sub> bed. Also, because of the generally massive structure and especially because of the abundance of fossils in the uppermost beds of the middle member, it was felt that these beds should be treated as a separate stratigraphic unit (unit 3) rather than as a subdivision (B<sub>4</sub>) of the underlying sequence of thin bedded, unfossiliferous

ferous rocks that are here assigned to unit 2.

Most of the fossils that have been previously reported to occur in the Bakken Formation by Canadian workers were also found in the cores of this study; these consist of fragments of pelmatozoan columns and five genera of brachiopods (Lingula, Orbiculoidea, Chonetes, Rhipidomella, and Spirifer). Crania is the only previously reported brachiopod genus from the Bakken (Brindle, 1960, p. 16) that was not found in this study. Another previously reported fossil occurrence not found here is the presence of chonetids in the lower shale member, which were reported by Christopher (1962, p. 75). The only American author who has identified macrofossils from the Bakken was Kume (1963), and most of his specimens were re-examined and re-identified in this study. His "fish scales ?" are valves of the conchostracan Cyzicus (Leioestheria) sp. and his "Cyrtospirifer (?) sp." is a brachial valve of Syringothyris hannibalensis that is partly embedded in the matrix. His assignment of Bakken rhynchonellids (from unit 1 to Camarotoechia was rendered obsolete by Sartenauer (1961c), who redefined that genus and restricted its range to the Middle Devonian; Kume's rhynchonellids were considered here to be too fragmental for identification. The conulariid he found appears to be a fragment of Paraconularia missouriensis but, as mentioned, the core this specimen came from might represent the Carrington shale facies of the Lodgepole Formation (Bjorlie, 1979, p. 45; Webster, 1982, p. 22). Kume's specimen of Orbiculoidea sp. was not seen in this study.

### Biostratigraphy

Each of the Bakken's fossiliferous zones appears to have a faunal equivalent that occurs in outcrop in either the east-central interior of the United States, the upper Mississippi Valley, or in the rocks of the

Bakken's depositional complex in the Western Interior. Most of these faunas from outcrops are thought to indicate particular segments of geologic time and thus these faunas in the Bakken suggest ages for most of the fossiliferous intervals of the formation. The ages thus determined for the Bakken Formation in North Dakota agree closely with the ages of the Bakken Formation as determined by regional evidence (e. g., Gutschick and Moreman, 1967; Gutschick and Rodriguez, 1979), macrofossil evidence (Brindle, 1967), conodont evidence (Hayes, 1984), and spore evidence in Alberta (Macqueen and Sandberg, 1970)

The macrofossils within the basal few feet of the lower black shale, such as the articulated brachiopods, conchostracans, gastropods and pelecypods, have not, with the exception of Rugaltarostrum montanensis, been reported to occur in the equivalent black shales in the Western Interior. The fauna does appear similar, however, to the benthic fauna that occurs locally near the base of the Devonian black shales in the eastern United States. This fossiliferous interval in the eastern United States is called the Blocher Formation of the New Albany Shale in Indiana (Conkin, et al., 1981, p. 5), and Campbell 1946, p. 867-868) reported that the fossils of the Blocher and its equivalents in other eastern black shales appear to represent two distinct and isochronous assemblages, a Schizobolus assemblage and a Leiorhynchus assemblage. The fossils from near the base of the Bakken appear to be related to the Leiorhynchus assemblage largely on the basis of the presence in the Bakken of Rugaltarostrum montanensis (originally assigned to Leiorhynchus) and the absence of the inarticulate brachiopod Schizobolus, which is the most common form in the Schizobolus assemblage. Also, Lingula sp. 2, Barroisella sp., and Straparollus (Straparollus) sp. 2 of the

Bakken appear similar to forms of the Leiorhynchus assemblage from the eastern United States, as illustrated by Girty (1898). Campbell (p. 841) reported that the Blocher is similar in lithology and fossil content to the Genessee Shale of New York and is, therefore (p. 842), probably of the same late Middle Devonian age. This age is much older than other evidence would indicate for the age of the Bakken (e. g., Gutschick and Rodriguez, 1979; Hayes, 1984, 1985). The Bakken forms are similar to, but not identical with, the forms illustrated from the eastern black shales, and perhaps they represent evolutionary descendants of the benthic fossils from the base of the eastern dark shales. This fauna in the Bakken Formation differs most conspicuously from that of the Blocher by the presence of C. (Lioestheria) sp. in the basal feet of the Bakken. The presence of this species at this interval appears to mark the first occurrence of C. (Lioestheria) sp. in rocks that have been dated (Hayes, 1984, 1985) as belonging to the Upper Polygnathus styriacus Biozone; as mentioned, Gutschick and Rodriguez (1979, p. 45) did not report this species to occur in rocks older than that of the Middle Bispathodus costatus Biozone, which is slightly younger than the Upper P. styriacus Biozone (Figure 4)

More conclusive macrofaunal evidence for a Late Devonian age for the lower shale member is suggested by the occurrence of Foerstia sp. over a three-foot interval in NDGS Well No. 4340, Williams County. This interval starts about five feet higher in the section than the top of the lowest fossiliferous interval and, as discussed, this important guide fossil of the Eastern Interior region was found in the Bakken at the same interval in which Foerstia sp. occurs in other late Devonian rocks. Upon its discovery in the Bakken, the stratigraphic interval in

which Foerstia sp. is known to occur was closely re-examined in 10 other cores, but without success. Nevertheless, the presence of Foerstia sp. in the lower black shale of the Bakken Formation seems to represent a time marker of Late Devonian age in the Williston Basin and suggests that this interval of the Bakken is of an age equivalent to that of part of the black shale member of the Exshaw Formation and part of many of the Upper Devonian black shales in the eastern United States, such as the Chattanooga, New Albany, and Ohio Shales.

The abundance and lateral persistence of Cyzicus (Lioestheria) sp. within the top few inches of the lower shale member, together with the lithology and stratigraphic position of this interval, closely resembles the widespread conchostracan bed found in the Bakken's depositional complex. The specific age of this bed apparently cannot be determined from the conchostracans themselves, as they were found to range in the Bakken from near the base to near the top of the formation; their occurrence in the upper shale member supports the contention of Macqueen and Sandberg (1970) that C. (Lioestheria) sp. extends into the lower Mississippian. The conchostracan bed at the top of the lower shale member of the Bakken Formation appears to be of a very late Devonian age, however, as is suggested by the presence of species of the Syringothyris fauna in the overlying rocks of the middle member, and the fact that Hayes (1984) found conodonts of Late Devonian age in the upper beds of the lower Bakken shale.

All of the taxa found in unit 1 of the middle member have been reported from the Syringothyris fauna of the Louisiana Limestone of Missouri by Williams (1943) or from the Sappington Member-Leatham-Leatham Member subcomplex of the western United States by Gutschick and Rodri-

guez (1967, 1979); most have been reported from both of these rock bodies. Ten brachiopod taxa (not including juveniles), eight of which are identified to species, were found in unit ; of these identified species, five (Rhipidomella missouriensis, Schuchertella lens, Orbinaria pyxidata, Tylothyris clarksvillensis, and Syringothyris hannibalensis) were found in both the Louisiana and the Sappington-Leatham-Leatham Member subcomplex; Orbiculoidea limata has not been reported from the Sappington and its equivalents (although a comparable form has been) and Schellweinella inflata and Rhytiophora arcuatus have not been reported from the Louisiana. Thirteen nonbrachiopod taxa were also found in unit and these consist mostly of several genera of poorly preserved or minute gastropods and pelecypods, an orthocerid nautiloid, C. (Leioestheria) sp., fragmental pelmatozoan columns, and the trace fossils Scalarituba missouriensis and Cosmoraphe sp.. Although most of these forms are not specifically identifiable, they, as a whole, and especially the trace fossils, closely resemble the nonbrachiopod fauna of the Louisiana Limestone and the Bakken correlatives in the western United States.

All of the mollusks and juvenile forms from unit 1 were found within the basal few feet of the unit and generally resemble the fossils from the greenish-gray shale below the Sappington siltstone (unit D) and the limestone at the base of the siltstone member of the Leatham Formation. As discussed, these beds in the western United States are considered to be of the Middle Bispathodus costatus Biozone, but this biozone is a partial time equivalent of the Siphonodella praesulcata Biozone (Figure 4) and brachiopods characteristic of the Syringothyris fauna occur in this interval of the Sappington and Leatham (Gutschick and

Rodriguez, 1967, p. 602; and 1979, p. 49). Similarly, this fauna in the Bakken is closely associated with the brachiopods of unit 1 but, unlike the Sappington and Leatham, this fauna in the Bakken occurs in the same lithology as the overlying rocks. The apparent confinement of this fauna within the basal few feet of the middle member could be due to the fact that this is where most of the fossils of unit 1 were found; this fact, and the general lack of specific identifications of this minute or nonbrachiopod fauna in the Bakken, Sappington, and Leatham, makes this correlation tentative

Gutschick and Rodriguez (1967, p. 601; 1979, p. 49) said that there are slight faunal differences in the Syringothyris assemblages of units E, F, and G of the Sappington and, based on these differences, the fauna of the Bakken Formation in unit 1 of the middle member appears the most similar to the fossils of unit E of the Sappington. This comparison is based on the presence of Schuchertella lens from near the top of unit 1, which Gutschick and Rodriguez (1967, p. 603) stated was restricted to unit E in the Sappington, and on the absence of Spirifer greenockensis in unit 1 of the middle member which Gutschick and Rodriguez found only in units F and G of the Sappington. Also, Rodriguez and Gutschick

(1967, p. 378-379) reported that forms that resemble Spirifer sensu stricto are common in unit F of the Sappington but are rare in unit E. Similarly, no specimen that resembles Spirifer s. s. was found in unit 1 of the middle member of the Bakken in this study, whereas specimens of Spirifer are abundant in unit 3 of the middle member. None of the oncolites that characterize unit E was found in the cores but, as mentioned, oncolites are not always found in correlatives of unit E of the Sappington.









Biostratigraphic control of unit 2 of the Bakken is limited by a general lack of macrofossils in this unit, and the fossils that do occur are mostly nondiagnostic. One correlation was made, however, between the blade-like leaves within the basal few feet of unit 2 and an abundance of "carbonized compressions of fragmentary blade-like 'leaves'" reported by Conkin and Conkin 1973, p. 25) to occur within the basal few feet of the Horton Creek Member (also known as the Glen Park member) of the Hannibal Formation in western Illinois. The lithologies in which these plants occur in the Bakken Formation would seem to be similar to those from western Illinois, as Conkin and Conkin 1973, p. 25) stated "These plants occur in thinly laminated, limy, argillaceous, dolomitic and/or silty shales." The plants from the Bakken and the Horton Creek also occur in thin beds of arenaceous siltstone. A significant factor concerning this correlation is that the plants in Illinois appear to occur at the base of the Siphonodella sulcata Biozone in the type lower Mississippian section and have been used by Conkin and Conkin 1973, p. 25) to mark the base of the Mississippian in the type Mississippian area. Indirect biostratigraphic evidence also supports such a correlation between the Bakken and Horton Creek; the brachiopod fauna of unit 1 indicates that these plants in the Bakken overlies rocks of latest Devonian age and the brachiopod fauna of unit 3 suggests that unit 2 underlies rocks of early, but not earliest, Mississippian age. Thus, as there is no evidence to the contrary, these plants in the Bakken are taken to mark the base of the Mississippian in the Williston Basin and at least the lower part of unit 2 is assigned to the S. sulcata Biozone of Early Kinderhookian age.

The Devonian-Mississippian boundary in the Bakken Formation thus

appears to occur at the poorly defined contact between units 1 and 2 in the middle member; no evidence of a disconformity, such as a paraconformous lag sandstone (Conkin and Conkin, 1973, 1979), was noted at this contact. The poor definition of this contact may be due in part to the little time that may have elapsed between the Siphonodella praesulcata Biozone and the S. sulcata Biozone in the Williston Basin, although apparently this hiatus was long enough for unit 1 to have been extensively reworked by burrowing infauna. If unit      correlates with unit E of the Sappington, then this period of reworking might have occurred during the deposition of units F and G of the Sappington. A further attempt to extract conodonts from this critical contact in the middle member of the Bakken is currently being conducted by Timothy P. Huber. Deposition of unit 2 may have occurred upward into the Lower S. duplicata Biozone, but evidence to support this was not found. A biostratigraphic analysis of the Bakken Formation that summarizes the information gained from this study is shown as Figure 8.

The abundant fossils of unit 3 comprise a brachiopod assemblage that, as mentioned, appears different from the Syringothyris assemblage of unit      The two faunas are somewhat similar, as five species (Lingula sp. 4, Orbiculoida limata, Rhipidomella missouriensis, Schuchertella lens, Orbinaria pyxidata, and Rhytiophora arcuata) of the 16 species of brachiopods found in unit 3 were also found in unit 1; thus, one-half of the brachiopod taxa found in unit      was also found in unit 3. Most of the common species of unit 3, however, (e. g., Chonetes gregarius, ?Allorhynchus heteropsis, and Spirifer sp.) were not found in unit      and some of the most characteristic brachiopods of unit 1, such as Tylothyris clarksvillensis and Syringothyris hannibalensis, were not

Figure 8. Biostratigraphic summary of the macrofossils of the Bakken Formation from western North Dakota. Thicknesses of the rock units are those of the type section. The conodont zones used are the conodont biozones commonly employed in the Western Interior (summarized by Sandberg, 1979).

| BAKKEN FORMATION   |               |   |  |                    |                      | KINDERHOOKIAN (part)                |  | MISSISSIPPIAN |
|--------------------|---------------|---|--|--------------------|----------------------|-------------------------------------|--|---------------|
| LOWER SHALE MEMBER |               | MIDDLE MEMBER   |  | UPPER SHALE MEMBER |                      |                                     |  |               |
| Lithosome          | Conodont Zone | L. & M. B. costatus   | Unit 1   | Unit 2             | Unit 3               | Upper S. duplicata - S. J. S. green |  |               |
| Lithology          |               | stylolite   | S. praesulcata   | S. sulcata         | Lower S. duplicata   | Upper S. duplicata                  |  |               |
|                    |               | Lingula sp. 3, orthocerid nautiloid, ostracod-like organism, fish fragments, possible plant fragments   | Lingula sp. 1, Orbiculoidea limata, Rhipidomella missouriensis minute chonetids and productids, indeterminate gastropod, Cyzicus (Lioestheria) sp., pelmatozoan columnals, fish fragments, woody plant fragment  |                    |                      |                                     |  |               |
|                    |               | Forstia sp. (in one core)   | Blade-like "leaves"  |                    |                      |                                     |  |               |
|                    |               | "Leiorhynchus" fauna; hylothyrid, Lingula sp. 2, Barroisella sp., Rugulastrostrum madisonense, Phragmosphaera sp., Straparollus (Straparollus) sp. 2, orthocerid nautiloid, coiled cephalopod, indeterminate pelecypods, ostracod-like organism, Cyzicus (Lioestheria) sp., fish fragments, Spirophyton-like trace fossil | Syringothyris fauna; Lingula sp. 4, Orbiculoidea limata, Rhipidomella missouriensis, Schellweinella inflata, Schuchertella lens, Orbinaria pyxidata, Rhytlophora arcuatus, indeterminate rhynchonellids, Tylothyris clarksvillensis, Syringothyris hannibalensis, Straparollus (Straparollus) sp. 1, Loxonema cf. L. missouriensis, orthocerid nautiloid, ?imitoceras sp., grammysian and prothyrid pelecypods, Cyzicus (Lioestheria) sp., pelmatozoan columnals, possible plant fragments, Cosmoraphe sp., Planolites sp., Sclerituba missouriensis |                    |                      |                                     |  |               |
|                    |               | Conchostracan bed: Cyzicus (Lioestheria) sp., eumalacostracan   | "Spirifer marionensis" fauna; Lingula sp. 4, Orbiculoidea limata, Rhipidomella missouriensis, Chonetes gregarius, C. ornatus, Rugosochonetes sp., Orbinaria pyxidata, Rhytlophora arcuatus ?Allo-rhynchus heteropsis, ?A. acutollicum, Composita spp. 1 & 2, Syringothyris halli, Spirifer greenockensis, Spirifer sp., Torynifer sp., indeterminate pelecypod, Brachymetopus (Brachymetopus) sp., pelmatozoan columnals   |                    |                      |                                     |  |               |
|                    |               | 8 ft. (2.44m)   |  |                    |                      |                                     |  |               |
|                    |               |  Shale   |  |                    |                      |                                     |  |               |
|                    |               |  Siltstone   |  |                    |                      |                                     |  |               |
|                    |               |  Sandstone   |  |                    |                      |                                     |  |               |
|                    |               |  Limestone   |  |                    |                      |                                     |  |               |
|                    |               |  brachiopods   |  |                    |                      |                                     |  |               |
|                    |               |  Scalarituba missouriensis   |  |                    |                      |                                     |  |               |
| Stg./Ser.          | System        |   | FAMENNIAN (part)   |                    | KINDERHOOKIAN (part) |                                     |  |               |
|                    |               |   | DEVONIAN   |                    |                      |                                     |  |               |

found in unit 3. Although most of the brachiopods of unit 3 have been reported to occur in the Syringothyris fauna of the Louisiana Limestone or in the Sappington and its equivalents, some of the species in unit 3 (such as Chonetes gregarius and Syringothyris halli have not been previously reported to occur in rocks older than Early Kinderhookian age (Carter and Carter, 1970)

A rock unit in the type Mississippian area in which C. gregarius occurs with S. halli is the McCraney Limestone of southeastern Iowa, northeastern Missouri, and western Illinois. Although Williams (1943) reported that the Syringothyris fauna of the Louisiana Limestone is distinctive with few of its taxa occurring independently of the assemblage, Stainbrook (1950, p. 199), in discussing the brachiopod fauna of the McCraney Limestone, stated, "Only one fauna was found to display any considerable similarity in specific and faunal composition. This is the fauna of the Louisiana limestone of Missouri and Illinois." He found the lithology and fossils of the McCraney and Louisiana to be so similar, in fact, that he considered the McCraney to be a part of the Louisiana Limestone. Much controversy ensued concerning the relative ages of these formations, as Scott and Collinson (1961, p. 110) wrote, "Few Paleozoic formations have in recent years been subject to more disagreement concerning their age and correlation than have the Louisiana and McCraney Limestones . . . ." Besides the similarity in lithology and fossils, Scott and Collinson (1961, p. 110) reported that another reason for the confusion between the Louisiana and the McCraney was that, "Even though the two formations occur in the same general area, they have never been positively identified in the same section, either surface or subsurface." Based on conodont evidence, Scott and Collinson (1961

demonstrated that the McCraney is of an early Mississippian age and is significantly younger than the Louisiana and thus resolved this controversy. Because unit 3 of the Bakken overlies the Syringothyris fauna of unit 1 and contains species from both the Louisiana Limestone and the McCraney Limestone, it would seem that the fauna of unit 3 is related to the McCraney fauna, and is thus considered here to be of nearly the same age as is the McCraney Limestone. Other brachiopods in unit 3 seem to support such a correlation, as Chonetes ornatus, is a common species in the McCraney (Stainbrook, 1950), and most of the rhynchonellids of unit 3 closely resemble Allorhynchus heteropsis from the McCraney Limestone.

Scott and Collinson 1961, p. 19) found that conodonts of the McCraney Limestone are dominated by the genus Siphonodella and consist entirely of Mississippian forms. They reported (p. 119) the presence of S. cooperi and S. duplicata in the McCraney; and Sandberg 1979, p. 98-99) reported that forms of these species occur together only in the Upper S. duplicata Biozone, in the overlying S. sandbergi Biozone, and in the lower part of the overlying Lower S. crenulata Biozone, all of which Sandberg 1979) reported to be of early, but not earliest, Kinderhookian age. Unit 3 of the middle member thus probably belongs to one of these three conodont zones. It is probably not of the Lower S. crenulata Biozone, however, since Hayes 1984, 1985) found rocks of this biozone near the top of the overlying upper shale member of the Bakken.

The history of the Spirifer marionensis fauna of the Exshaw Formation is similar to that of the McCraney fauna in that the S. marionensis fauna was also thought to be a correlative of the Syringothyris fauna of the Louisiana Limestone until later conodont and physical evidence suggested (Macqueen and Sandberg, 1970) that the Exshaw, like the McCraney,

is of an early, but not earliest, Kinderhookian age and is thus significantly younger than the Louisiana. Although the Spirifer marionensis fauna of the Exshaw siltstone has never, to my knowledge, been directly correlated with the brachiopod fauna of the McCraney Limestone, such a correlation appears to be indicated by this study; besides correlating with the McCraney Limestone, the brachiopods of unit 3, as well as the stratigraphic position and brachiopod age assignment of the unit, are suggestive of a correlation of this unit with the S. marionensis Biozone of the Exshaw Formation.

Although, as mentioned, Harker and McLaren (1958, p. 251) stated that brachiopods of the Exshaw are not specifically identifiable, Warren (1937, p. 456) listed eight species, all of which are forms similar to those found in unit 3 of the Bakken. A few of his species also resemble forms from the Syringothyris fauna of unit 1 of the Bakken, which perhaps reflects the similarity between the Louisiana and McCraney faunas and, equivalently, the Sappington and Exshaw faunas. Warren (1937) listed three species of Spirifer from the Exshaw; two of these were reported by Brown (1952) as being similar to S. greenockensis, and one (S. centronatus), resembles the forms assigned here to Spirifer sp.. Warren's faunal list also included Orbinaria concentrica and Composita humilis and both of these may be conspecific with species from the Bakken, as is explained in the section on systematic paleontology. He also listed three species of rhynchonellids that are generally similar to the rhynchonellids found in unit 3 in North Dakota.

The brachiopod fauna of unit 3 also seems to resemble the part of the S. marionensis Biozone that overlies the Exshaw and Bakken Formations in Canada, as some of the species that occur in unit 3, such as

Chonetes gregarius and Spirifer greenockensis, are also found in the "middle member" of the Banff Formation in Alberta and in the Souris Valley and Tilston beds of the Lodgepole (Banff Formation) in Saskatchewan (Brown, 1952; Brindle, 1960). The faunas of unit 3 and the Exshaw differ most conspicuously from overlying faunas by the general absence of corals and pelmatozoans in the former.

The Bakken Formation thus appears to contain both the Syringothyris fauna of the Louisiana Limestone and the Sappington-Leatham-Leatham Member subcomplex and the Spirifer marionensis fauna correlatable with the McCraney Limestone and found in the Exshaw Formation. As these faunas have never been found together in the same section, their presence in the Bakken Formation appears to represent a unique situation; the vertical succession of these faunas in the Bakken appears to demonstrate conclusively that the S. marionensis fauna is younger than is the Syringothyris fauna

The rare and poorly preserved macrofossils in the other rocks of known or questioned Mississippian age in the Bakken's depositional complex, such as unit H of the Sappington, the Englewood Formation, and the upper Pilot Shale have been too poorly studied for any comparisons with the unit 3 fauna to be made here

Macrofossils in the upper shale member were too rare for biostratigraphic work and most, such as Lingula sp. 1, Orbiculoidea limata, and Cyzicus (Lioestheria) sp., are not age-diagnostic and others, such as the snail and pelmatozoan remains, are too poorly preserved for proper identification. The only fossil found in the upper shale that may relate to a previously established biozone is the woody plant fragment found by Webster (1982) This specimen, which is too fragmental for gen-



eric identification, may belong to one of more than 25 genera of terrestrial plants that Cross and Hoskins 1951 reported to occur in the lower Mississippian black shales of the Eastern Interior region.

#### Depositional Setting

##### Facies Control

The fossils of the Bakken Formation appeared to be randomly distributed within the various biosomes and thus showed little evidence for facies control. A lack of facies control in the Bakken is also evidenced by the similarity of the lithologies of the Bakken beds seen from core to core in this study; Fuller (1956, p. 24) stated, "The great extent and lithological constancy of the twin black shales and medial arenaceous beds of the Bakken Formation at once reveal a very uniform depositional environment." Such uniform environments for the Bakken biosomes suggest that the apparent lateral confinement of the conchost-racan bed and the blade-like leaves to the depocenters of their respective units is due to intraformational erosion rather than to environmental control. Both of these units are very thin and occur at the bottom or top of their respective rock units, and thus appear to form sensitive indicators for detecting the disappearance of those units toward the margins of the formation; the area in which the conchostracan bed and blade-like leaves occur together appears to mark the area in North Dakota in which the Bakken section is most complete. Figures 9 through 13 are areal distribution maps of a representative taxon from each of the Bakken's five fossiliferous intervals. The control points on each map represent all of the available cores of that particular interval.

The lateral persistence of the faunas was especially evident in

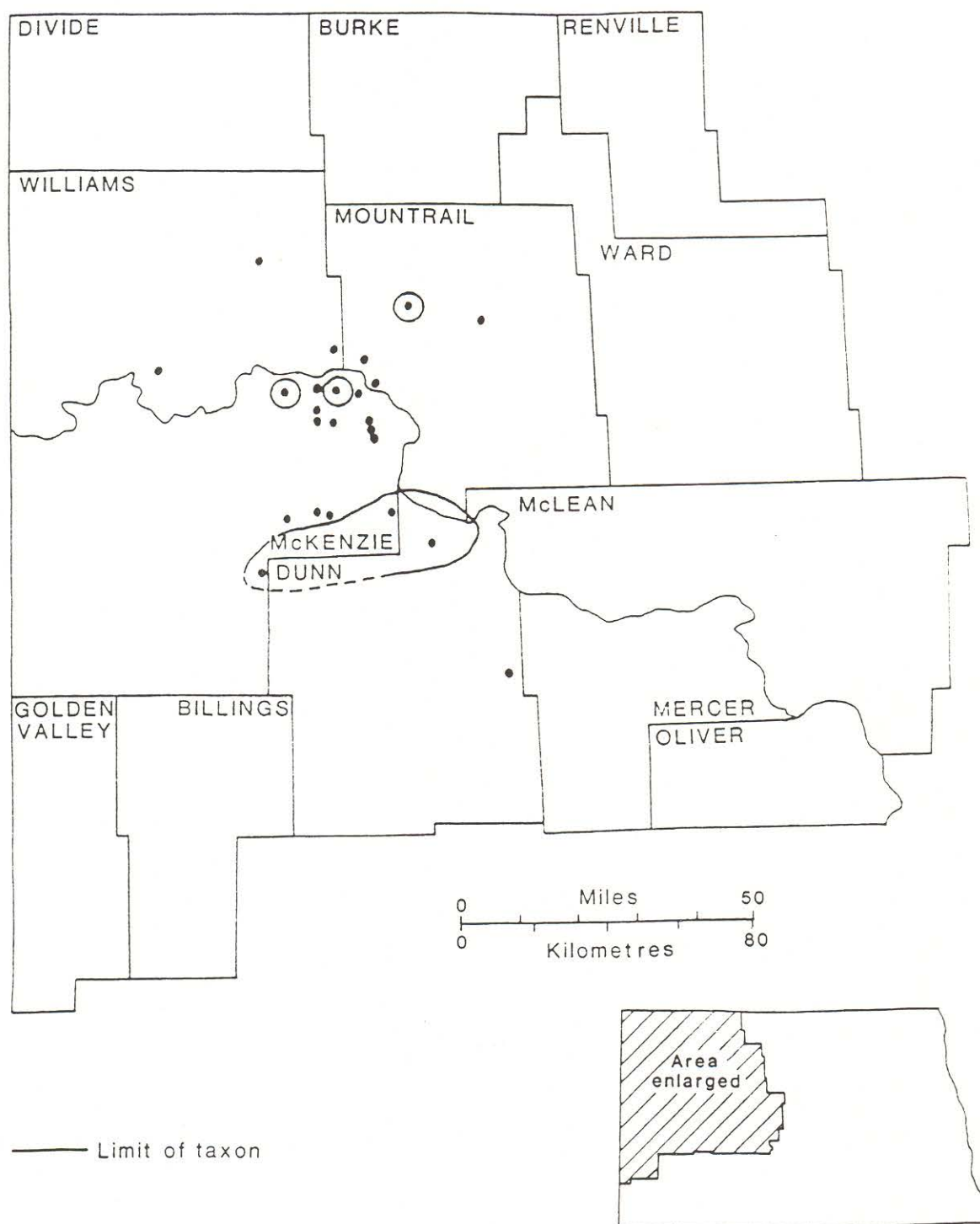


Figure 9. Distribution of *Barroisella* sp. from the lower shale member of the Bakken Formation.

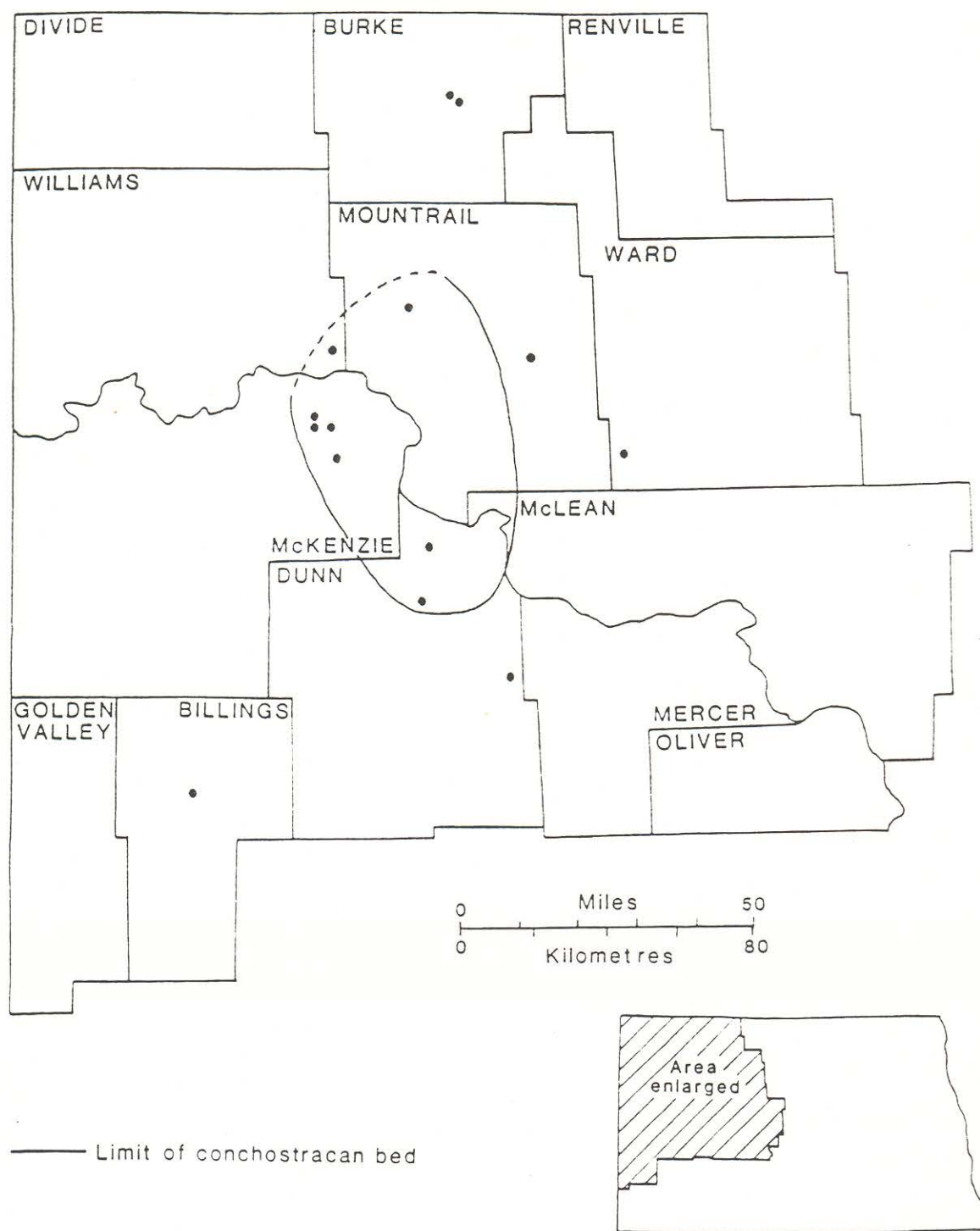


Figure 10. Distribution map of the conchostracan bed at the top of the lower shale member of the Bakken Formation.

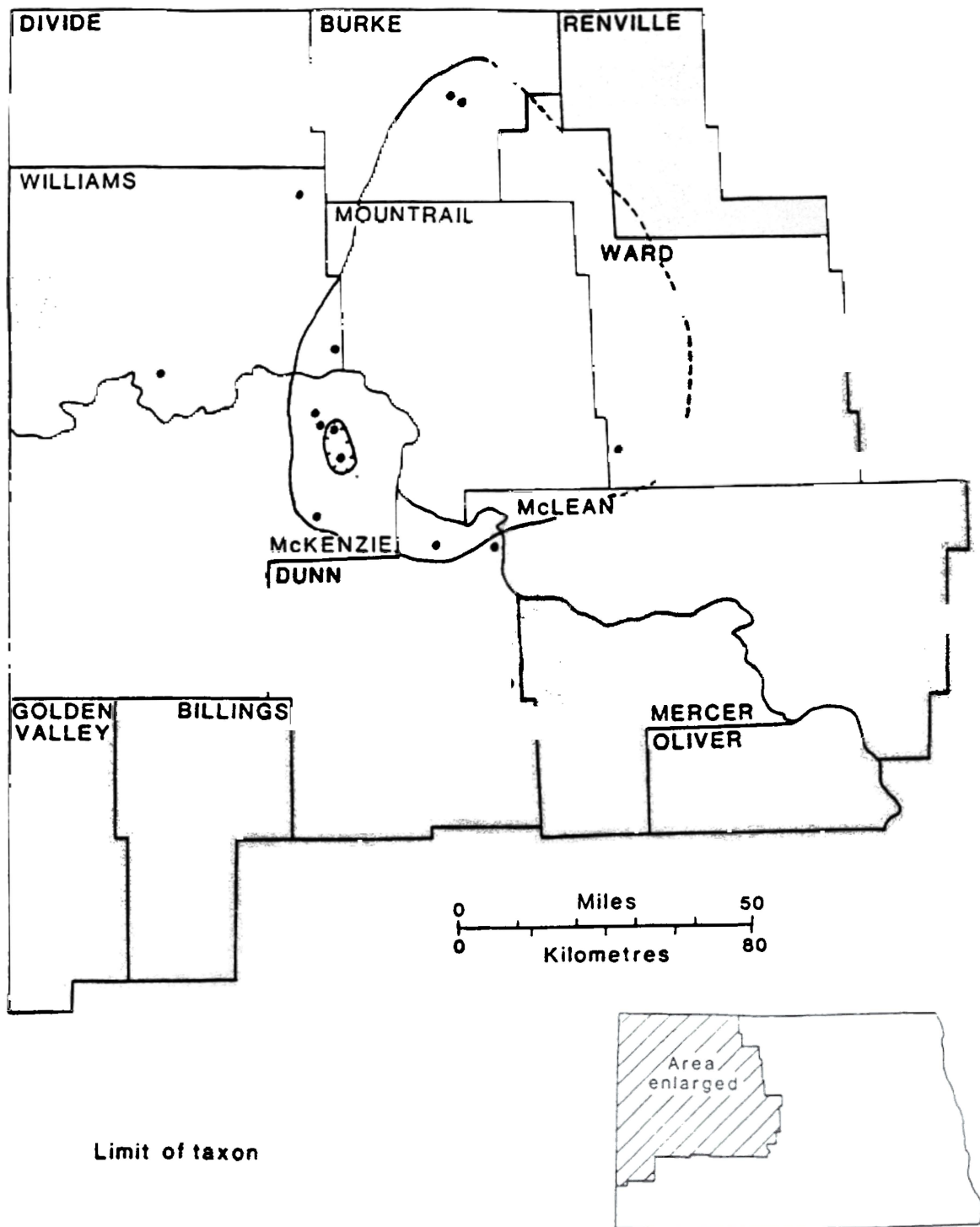


Figure 11 Distribution map of *Rhipidomella missouriensis* from unit 1 of the middle member of the Bakken Formation. No specimens were found in the area of enclosed hachures.

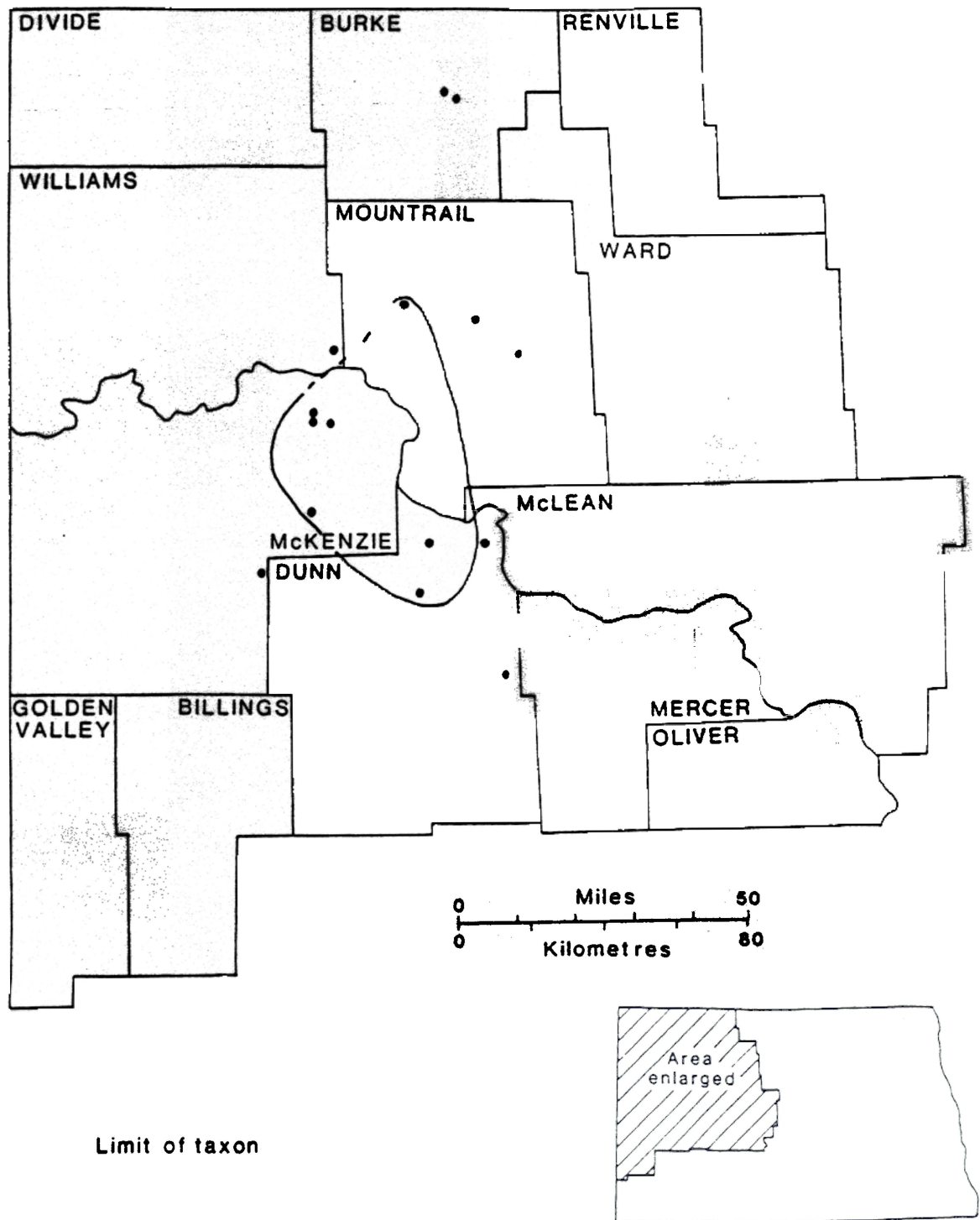


Figure 12 Distribution map of blade-like "leaves" from unit 2 of the middle member of the Bakken Formation.

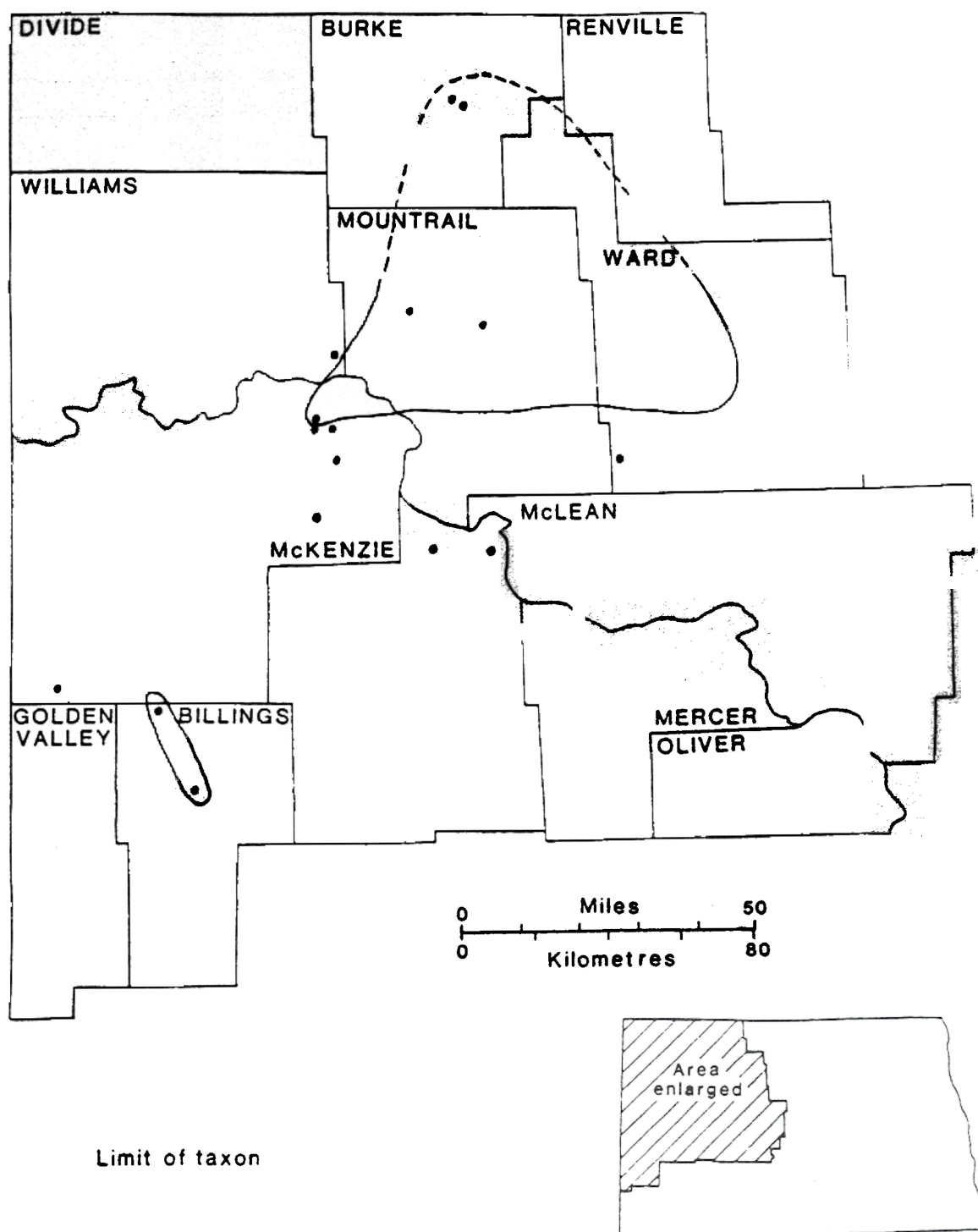


Figure 13 Distribution map of *Chonetes gregarius* from unit 3 of the middle member of the Bakken Formation.

3, as this was the most areally extensive fossiliferous interval of the Bakken Formation in North Dakota. The taxa of unit 3 in the Central Area were the same as those found in the top three to five feet of the middle member in cores from near the Marginal Shelf, where the Bakken middle member is only about 10 feet thick. The top of unit 2 also appears to be present in these cores from the margins, for the bottom few feet of the middle member in these cores (NDGS Well Nos. 105 in Ward County, 7579 in McKenzie County, and 7887, 8474, and 935 in Billings County) consist of unfossiliferous, fine-crystalline limestone or dolomitic siltstone that in places, contains thin bedding. The absence of the Syringothyris fauna of unit in these marginal cores further indicates that it is the lower beds of the middle member that thin out and disappear first toward the Marginal Shelf; this is indicated on the cross sections of the formation shown in this study (Figures 2 and 7)

#### Depositional Environments

The different lithologies and associated change in faunas seen in the Bakken Formation represent a vertical sequence of several different environments that appear to represent geographic extensions of previously known biofacies; thus studies on the depositional environments of those biofacies are germane here. Similarly, previous studies of rocks that resemble the unfossiliferous parts of the Bakken (i. e., most of the black shale members and much of the middle member) are also pertinent to this study.

The depositional environments of the Bakken black shales are related to widespread environmental conditions that led to deposition of the Upper Devonian-Lower Mississippian black shales across much of the craton. In speaking of these shales, Ettensohn and Barron 1981, p.

349) said, "Although the specific conditions under which black shales accumulate are fairly well known, the regional controls that permitted these conditions to develop are not as well known." They then developed a depositional model for the black shales based on previously determined paleogeographic and paleoclimatic conditions of the craton that occurred in combination with eustatic changes in sea levels and tectonic activity of the Antler and Acadian orogenies

Based on the accumulated knowledge of more than 25 years of extensive biostratigraphic work in the western United States, Sandberg, et al. (1983) developed a depositional framework for the rocks of Middle Devonian through Late Mississippian age in the Western Interior that is based on eustatic changes in sea level. Their detailed discussion of sea level changes in the Late Devonian and Early Mississippian provides a framework for the conditions in which the rocks of the Bakken's depositional complex were deposited; their work agrees well with the depositional model of Ettensohn and Barron 1981 and with the evidence seen in this study.

Sandberg, et al. (1983, p. 703-704) reported that prior to the deposition of the lower black shale members in the Bakken's depositional complex, the Three Forks Formation and equivalent rocks were deposited during an early Late Devonian eastward transgression of the sea that lasted through the Upper Scaphignathus velifer Biozone. This transgression was followed by a regressive phase of non-deposition and erosion that, in the Sappington-Leatham-Leatham Member subcomplex, is thought (Sandberg, et al., 1980) to have lasted through the Middle Polygnathus styriacus Biozone. Sandberg and Hammond (1958, p. 2331) reported that uplift and erosion around the margins of the Williston Basin during this



time is evidenced by the disappearance of the upper beds of the Three Forks near the basin margins. They said further (p. 2328) that intermittent uplifting of the basin margins, together with the persistent subsidence of the basin, are the two major factors controlling sedimentation in the Williston Basin.

Sandberg, et al. 1983, p. 704) reported that the lower shale members of the Bakken's complex were deposited during a relatively rapid transgression that occurred in concert with Antler orogenic activity (such as crustal downwarping) during the time of the Upper Polygnathus styriacus Biozone. They stated further (p. 704) that this transgression caused dark shales of the Bakken's depositional complex to be deposited far to the east of older rocks; Ettensohn and Barron (1981, p. 349)

"Between the Acadian and Antler belts, a large expanse of low-lying craton was partially covered by epicontinental seas during the Late Devonian." Evidence cited by Ettensohn and Barron (1981, p. 349) for this transgression in the eastern United States includes "the progressive onlapping of black shale units from the Appalachian basin onto the Cincinnati arch." Evidence for this late Devonian transgression is seen in the Williston Basin by the sharply disconformable Three Forks-Bakken contact near the margins of the basin, indicating that the Three Forks was exposed to erosion near the margins of the basin prior to black deposition (Fuller, 1956; Christopher, 1961).

The Three Forks-Bakken contact was seen in 18 cores and in 14 it was sharp; rip-up clasts or other erosional features were seen at this contact in three cores from near the center of the basin (NDGS Well Nos. 1679, 1858, and 2602 in McKenzie County) and in one well from near the southern margin of the basin (NDGS Well No. 9351 in Billings County),

which has a thin, conglomeratic, conodont-bearing sandstone at the base of the lower shale (Hayes, 1984, p. 54). This contact was not seen in other cores from near the margins of the basin. Perhaps the erosional Three Forks-Bakken contact seen in three cores from the central part of the basin is indicative of the hiatus that is suggested by regional evidence to occur between the Three Forks and Bakken (Sandberg and Poole, 1977). Physical evidence of this unconformity is typically evidenced in the Western Interior by the basal sandstone of the lower black shale members, but such evidence was generally absent in the Bakken cores of this study.

Various depositional models for the formation of the Devonian-Mississippian black shales (e. g., Byers, 1977; Demaison and Moore, 1980) suggest that the high amount of organic matter preserved in the Devonian-Mississippian black shales, along with the lack of "clastic dilution" of these shales, "apparently reflect high organic productivity, low clastic influx, and development of anaerobic conditions in a stratified water column" (Ettensohn and Barron, 1981, p. 344). Ettensohn and Barron (1981, p. 344) reported that such conditions occurred in sediment-starved basins that, they proposed, contained progressively deepening seas due to the on-going transgression. They stated (p. 354), "During initial phases of transgression onto the craton, the black-shale sea was relatively shallow. These shallow water deposits, however, are usually poorly developed or condensed into a basal lag zone due to the rapidity of transgression and the low-lying nature of the surface over which transgression occurred."

Although a basal lag zone was generally absent in the Bakken cores, evidence of an initially shallow-water, aerobic sea is seen by the pres-

ence of the benthic fossils that occur locally in the basal few feet of the lower black shale member. Ettensohn and Barron (1981, p. 350) stated, "It is possible for organic matter to be preserved in an oxidizing environment wherever organic matter accumulates in such abundance and so fast that organisms and oxidizing processes cannot decompose all the mass . . . . Such conditions are apparently represented in basal parts of the black-shale sequence, where benthic faunas occur locally." They said that these conditions occur "in water shallow enough to allow vertical mixing and replenishment of oxygen . . . . The presence of such a fauna at the base of the Bakken Formation thus seems to establish a high degree of similarity between the initial conditions of deposition of Devonian black shales in the Williston Basin with those in the Eastern Interior region. This benthic fauna in the Bakken Formation, like those in the eastern dark shales, consists entirely of epibenthic forms; no evidence of infaunal forms was noted in this interval of the Bakken. Ettensohn and Barron (p. 350) suggested that this lack of infauna is evidence that "reducing conditions rapidly set in below the sediment-water interface."

Ettensohn and Barron (1981, p. 354) stated, "as transgression and deepening continued throughout the Late Devonian, the cratonic sea deepened sufficiently that a pycnocline [density gradient] was established throughout the sea, and black, organic-rich muds accumulated even on the cratonic highs." Paleontologic evidence for a deepening of the seas includes the lack of benthic fossils throughout most of the black shales and the presence of a wide-platform, palmatolepid conodont fauna, which Ettensohn and Barron (p. 354) reported has been found to indicate deep water in a number of studies. Sandberg, et al. (1983, p. 704) stated

the lower black shales of the Bakken's depositional complex contain a deep-water, palmatolepid conodont biofacies and Hayes (1984, p. 85) noted that, as a whole, the conodonts from the lower Bakken shale in North Dakota closely match this deep-water biofacies of the western black shales.

Ettensohn and Barron (1981, p. 354) said that the black-shale seas became deep enough for upwelling to occur locally along the coasts of

craton. Evidence they cited for the presence of upwelling include beds of radiolarian chert, which are common in all of the lower black shales of the Bakken's depositional complex (Gutschick and Rodriguez, 1979, fig. 13), but none was found in this study. They reported that other evidence of upwelling includes the presence of thin, bioturbated green shales within the dark shale sequence, but such shales were also

seen in this study. Some green shale that was reported to occur in the lower Bakken shale by Hayes (1984, p. 54) in NDGS Well No. 8177 (Ward County) appears to be a clay alteration product on a few chips of black (N1) or dark gray (N2-N3) shale. Besides sufficient water depth for upwelling to occur, Ettensohn and Barron (1981, p. 354) pointed out

appropriate paleogeographic factors for prevailing offshore winds would also be necessary; Webster (1982, p. 34) suggested that conditions for this to occur were probably not ideal in the Bakken sea, but inspection of the maps of Heckel and Witzke (1979) indicates that the upwelling they showed may well be extended into the area of the Williston Basin.

Ettensohn and Barron (1981) reported that a number of studies have suggested a minimum water depth of 700 feet for the Devonian-Mississippian black shales, although there is still debate regarding this ques-

tion. For example, Conkin, et al. (1980, p. 3) regarded the eastern black shales to represent "shallow to medium-shallow deposits." Kohlberger (1983, p. 9) summarized this debate on the Devonian-Mississippian black shales by stating, "The failure of workers to distinguish relative depth of sediment in the facies sequence from absolute depth in approximate numbers of feet or meters may be responsible for 90% of the debate on this question."

Ettensohn and Barron (1981, p. 349) reported that one of the most prevailing climatic factors concerning deposition of the Devonian-Mississippian black shales is that, at that time, the North American craton was part of the Laurasian supercontinent; they said, "Most workers agree that Laurasia was an equatorial landmass during the Devonian". They added (p. 350) that this landmass "was largely a carbonate terrain, was covered with vegetation, and was low in relief, having been nearly peneplaned during a period of regional uplift and erosion separating the Middle and Late Devonian." The high organic content of the dark shales was derived (Ettensohn and Barron, 1981, p. 350) from large influxes of terrestrial vegetation from the nearby craton into the black-shale seas and by prolific growth of plankton seen in most equatorial seas

Ettensohn and Barron (1981, p. 348-350) reported that rocks of the black shale facies in North America were deposited in partly enclosed, epicontinental seas whose circulation was restricted, in part, by the offshore Acadian and Antler Mountains. The lack of clastic dilution of the organic material was caused (Ettensohn and Barron, 1981, p. 344) by "sediment starvation" due to the low-lying craton and, at least for the eastern black shales, because the rising, off-shore mountains of the Acadian orogeny " . . . not only effectively enclosed the sea but also

created an orographic barrier crossing the belts of moisture-laden trade winds, forming a rain shadow west of the mountains and reducing clastic input into the black-shale sea." Preservation of this organic matter is thought to have been due largely to the anaerobic environment, which led to an absence of scavengers that normally break down the organic material. Twenhofel (1939, P. 1186) reported that abundant pyrite in the black shales is evidence of the accumulations of sulfides in the black-shale sea. He stated that the sulfides were derived from the organic matter and sea water, and caused toxic conditions to develop in the anaerobic, stagnant seas.

Ettensohn and Barron (1981) suggested that a pycnocline was established in the black shale seas by the restriction of both horizontal and vertical currents. The anaerobic condition of the seas resulted, in part, from a density-stratified water column which, in turn, further inhibited currents. They stated (p. 353), "Prevention of horizontal mixing at depth usually requires a sill or bar near the entrance of the sea . . . or the sea may be divided into a series of deeper basins separated by broad, higher rises or thresholds . . . " An apparent lack of sills in the eastern dark shales suggested to them (p. 353) that the eastern black shales were formed in separate basins of the same sea that may have shared surface waters but not deeper waters. Evidence they cited for this lack of sharing of the deeper waters included the slightly different facies and lithologies seen in many of the black shale sequences. A sill may have restricted the circulation of the Bakken sea, as was discussed by Kume (1963, p. 45), who stated that deposition of the Bakken " . . . probably can be attributed to the control of circulation of this . . . sea by tectonic activity in southern

Alberta and south-central Saskatchewan. During times of tectonic activity, a threshold, shelf, or some other submarine barrier could have existed and restricted the free circulation of the sea."

The development of anaerobic conditions in a density-stratified water column also requires restrictions of the vertical currents of the

Ettensohn and Barron (1981, p. 351 reported that the most significant form of vertical mixing is produced by thermal currents caused by the sinking of cooler surface waters. They stated (p. 35 "In warm, equatorial climates like that indicated for the black-shale sea, surface water rarely cools enough to sink to deeper levels and displace colder bottom waters, so that a layer of warmer, lighter, oxygenated water is formed near the surface." They added (p. 353),

Vertical stratification may also result from or be enhanced by a salinity gradient . . . Because the sea was equatorial, at least periodically large amounts of rain and runoff would have formed a lighter, less saline layer in parts of the sea. The presence of supposed brackish- to marine, pelagic algae such as Tasmanites and Foerstia throughout all or parts of the black shale support this contention.

The presence of this flora in the lower shale member of the Bakken thus further establishes a high degree of similarity between the environments of the Bakken Formation and the eastern black shales of Late Devonian age

The abundance of Cyzicus (Lioestheria) sp. at the top of the dark shale suggests that the lower Bakken shale was formed in shallow water near the end of its deposition. Gutschick, et al. 1976, p. 103) stated that such concentrations of this conchostracan at the top of the lower black shale in outcrop "represents an extremely shallow, quiet-water, near-shore, marsh-like deposit of great lateral extent." Gutschick and Sandberg 1969) stated, "a brackish water environment is suggested for

these latest Devonian conchostracans. Optimum conditions apparently were a muddy bottom, restricted circulation, shallow and quiet water, and slow deposition." There seems to be some question regarding the water depths of this biosome, however, as Sandberg and Gutschick (1979, p. 127) reported that conodonts from the conchostracan bed in the western United States represent an offshore, open marine, palaeolepid-polygnathid biofacies of the Middle Bispathodus costatus Biozone fauna.

Sandberg, et al. (1983, p. 707) reported that an hiatus occurred at the end of black shale deposition within the Sappington-Leatham-Leatham Member subcomplex, and that this hiatus was followed by an eustatic drop in sea level, resulting in a westward regression of the seas in the Western Interior during the time of the S. praesulcata Biozone. This regression is evidenced in the Bakken's depositional complex by a westward offset of the Syringothyris-bearing siltstone beds from the underlying black shale members and by (p. 707) "the shallow-water biota, ichnofossils, and lithologic character of the upper parts of the Sappington Member, Leatham Formation, and the Leatham Member of the Pilot Shale" (Sandberg, et al., 1983, p. 707). The Bakken middle member shows similar evidence for being a shallow water deposit, but no evidence other than the Syringothyris fauna has been found to suggest that the middle member is a regressive deposit; in fact, the middle member is generally considered (e. g., Webster, 1984, p. 64; Hester and Schmoker, 1985, p. 2) to be a transgressive deposit because of its onlapping relationship with the underlying rocks. The separation of the middle member into units 1, 2, and 3 appears to resolve this discrepancy, however, since the Syringothyris fauna was found only in unit 1 and this unit was found to be the least extensive unit of the Bakken Formation in North



Dakota (Figure 7). Unlike units 2 and 3, unit 1 was not found to overlap the lower black shale and was the only Bakken unit not found in the cores from near the margins of the formation. Unit 1 thus appears to be a regressive deposit that represents the low stand of the Bakken seas. Christopher's subdivision of the middle member also seems to show this regression, as he indicated (1961, fig. 19, pl. 5) that his "A bed" is the least extensive stratigraphic unit of the Bakken in Saskatchewan

Erosion in the basin during this low stand may have removed the top beds of the lower shale member, and thus the conchostracan bed, in the cores from wells outside of the depocenter of the lower black shale in North Dakota. No other evidence of a disconformable contact between the lower Bakken shale and the overlying middle member was seen in the cores of this study, although this contact was not seen in cores from near the margins of the basin. The lower shale-middle member contact was sharp in six cores (NDGS Well Nos. 2618 in Dunn County, 2820 and 3167 in McKenzie County, 4958 in Burke County, 8069 in Mountrail County, and

in Ward County) and transitional over a few inches in NDGS Well Nos. 607 in McKenzie County, 4508 in Burke County, and 5088 in Mountrail County.

The rocks and fossils of unit of the Bakken, like those of the other Syringothyris-bearing beds of the Western Interior, suggest a moderately- to well-oxygenated, shallow-water environment. This environment apparently became somewhat dysaerobic at times, as evidenced by

greenish gray rocks in unit 1 and by the general presence of pyrite and other sulfides in the matrix and on the fossils. Rodriguez and Gutschick (1970, p. 414) noted that the predominance of suspension feeders in the Syringothyris fauna "is suggestive of an intertidal or shallow

sublittoral habitat", and Conkin and Conkin 1968, p. 5) regarded Scalarituba missouriensis as "having been formed by a marine worm living in shallow water, probably in tidal flats, but certainly not in a deep-water environment."

The numerous brachiopods of unit 1 of the middle member of the Bakken are randomly oriented and are mostly disarticulated; this suggests post-mortem current transport followed by rapid burial, and they may represent storm deposits. Further evidence of rapid sedimentation in this part of the Bakken is suggested by a lack of an epifauna on the shells. Such an epifauna commonly occurs on shells from the Sappington Member of the Three Forks Formation and the Leatham Formation (Rodriguez and Gutschick, 1975) but epizoans are not present on the shells from the Leatham Member of the Pilot Shale and this absence was attributed by Gutschick and Rodriguez 1977, p. 198) to rapid sedimentation and burial of the shells.

Sandberg, et al. 1983, p. 707) reported that following the regression of the Siphonodella praesulcata sea, a relatively long period of continental stability lasted into the Early Mississippian and that during this time the seas were at a low stand and the surrounding land areas were generally flat. Epicontinental seaways in the western United States were narrow, shallow, and ephemeral during this period (from the S. sulcata Biozone through the S. sandbergi Biozone) and deposits of this age are rare in the Western Interior; they are confined mostly to the upper Pilot Shale in Nevada and the Cottonwood Canyon Member of the Madison Formation in Wyoming.

The paleontology and stratigraphic positions of units 2 and 3 of the middle member of the Bakken suggest that deposition also continued

at least periodically, in the Williston Basin during this time of Early Mississippian tectonic stability. Both units 2 and 3 of the Bakken appear to represent shallow water, transgressive deposits that overstep the underlying rocks. Christopher 1962, p. 76) said of equivalent rocks in Saskatchewan:

In general, the sediments of the Middle Bakken B bed were laid down in shallow water of variable current activity . . . gray black muds laminated with subordinate low angle cross-bedded and channelled very fine sand apparently reflect a sea floor of flats, shoals, and broad hollows traversed by weak, shifting currents.

The general similarity of the rocks and fossils of unit 3 with those of unit 2 suggests a similar depositional environment for these two units. This general kind of relationship has also been noted in the McCraney and the Louisiana Limestones, as Scott and Collinson (1961, p. 111) stated, "The remarkable lithic similarity of the two formations indicates that they represent similar environmental conditions. It is not surprising therefore that the benthonic faunas of the two formations are so similar." The currents in unit 3 were apparently stronger than those in unit 1, as the brachiopods of unit 3 are generally well sorted by size, are mostly disarticulated, and are commonly aligned with, and concentrated in, thin, well-sorted beds of mostly gray siltstone or very fine-grained sandstone. The sorting of the shells by size in unit 3 has led to concentrations of predominantly one species in individual beds; such concentrations are local and in some cores unit 3 is poorly fossiliferous. This localization of the unit 3 fauna was seen best in NDGS Well Nos. 4508 and 4958 (Burke County), which are about two miles from each other, and fossils are abundant in unit 3 in 4958 but rare in 4508. The fact that unit 3 contains more primary bedding structures than does unit 1 may be due, at least in part, to the lack of trace fossils and

bioturbation in unit 3.

Sandberg, et al., 1983) reported that following the period of general tectonic quiescence and erosion, "A major eustatic rise in sea level that resulted in onlap of the North American craton began in the Lower Siphonodella crenulata zone . . . . Ettensohn and Barron 1981, p. 357 wrote, "In the Early Mississippian the black-shale sea attained its greatest geographic extent . . . . Large-scale orogenic movements at this time in the Antler and Acadian belts resulted in depression of the entire central portion of the craton and eustatic rise in sea level

Sandberg, et al. (1983) reported that this transgression in the western United States is evidenced in part by extensive eastward onlap of the Cottonwood Canyon Member of the Madison Formation onto underlying units. This transgression is evidenced in the Williston Basin by the eastward onlap of the upper Bakken shale onto the older rocks, and by the fact that the upper shale member is the most laterally extensive unit of the Bakken in North Dakota; this member appears to represent the high stand of the Bakken seas.

As in the case of the Bakken cores from Canada, evidence of the regional unconformity that separates the Mississippian black shale members from the underlying siltstone members in the Bakken's depositional complex was generally not seen in this study. The middle member-upper member contact of the Bakken was seen in eight cores and, of these, only one from near the southern margin of the basin (NDGS Well No. 7579, McKenzie County) seems to show possible evidence of an unconformity; this core has a conglomeratic sandstone less than one inch thick that separates the middle member from the upper shale member. Two other cores from near the southern margin (NDGS Well Nos. 7887 and 9351, Bill-

ings County) do not appear to show evidence of erosion at this contact, however, as, in these cores, the middle member-upper member contact is sharp or gradational over a few inches

Gerhard, et al. (1982, p. 996) suggested that sometime near the Devonian-Mississippian boundary, a reorientation of the sea occurred in the Williston Basin, causing the Mississippian rocks to have a different, more widespread pattern of deposition with a less well-defined depocenter than that seen in the underlying rocks of the basin. This reorientation seems to become first evident in unit 3 of the middle member; as mentioned, this unit and the upper shale member appear to be structurally parallel with the transgressive rocks of Mississippian age that overlie them, whereas unit 2, also a transgressive deposit, appears to have the same structural configuration as the underlying Devonian rocks (Figure 7). The apparent confinement of the blade-like leaves of

2 to the central portion of the basin would suggest that the lower beds of this unit disappear quickly toward the margins of the basin.

Sandberg, et al. (1983) reported that the transgressive period in which the Mississippian black shales were deposited was relatively brief and extended into the time of deposition of the Lodgepole Formation. Conodont evidence for a nearly isochronous age for the upper beds of the Cottonwood Canyon Member and the lower part of the Lodgepole in Utah and Wyoming has been reported by Sandberg and Gutschick, 1979, p. 127); and

(1984, p. 93) stated that the conodonts from the upper few feet of the upper Bakken shale strongly suggest continuous deposition with the overlying Lodgepole Formation in North Dakota. The Bakken-Lodgepole contact was noted in only two cores of this study (NDGS Well No 793 in McKenzie County and NDGS Well No. 5088 in Mountrail County) and both

---

have a transitional contact a few inches thick.

The lithology and fossils of the upper shale of the Bakken suggest an environment similar to that of the lower shale, although evidence of bottom habitats suitable for life was less prevalent in the upper Bakken member than in the lower. Although a few benthic taxa were found in the upper black shale, most, such as the inarticulate brachiopods and pelmatozoan columnals, are of exceptionally small size; Twenhofel (1939, p. 1185) said that such small fossils in a black shale lithofacies generally represent immature, planktic forms that may have lived in plant floatant in well-oxygenated surface waters

#### Time Transgression

No evidence was seen in this study, or in the study by Hayes (1984), of time transgression of the Bakken units. Regional evidence also suggests nearly isochronous deposition of each of the separate Bakken units. An argument that the Bakken is time transgressive was made by Lineback and Davidson (1982), however. They stated that the Bakken dark shales represent the anaerobic, relatively deep water part of the basin, the middle member and Three Forks Formation represent a dysaerobic, shallower water facies closer to shore, and the Lodgepole Formation represents well-oxygenated and well-lighted waters around the basin margins, where coral and pelmatozoan growth was prolific. Based on electric log correlations, Lineback and Davidson (p. 126) stated that "the Bakken grades laterally into the Three Forks"; and thus, for convenience, they regarded the rocks of the middle member of the Bakken that extend beyond the limit of the lower shale member (the Shelf Margin) as part of the Three Forks Formation. While the Bakken has been reported (Fuller, 1956; Christopher, 196 ) to grade into rocks that

resemble the Three Forks near the margins of the basin, no workers other than Lineback and Davidson have suggested that the Bakken grades into the Three Forks; and no evidence for an isochronous age between the Three Forks and Bakken, such as an intermingling of the faunas, was seen in this study. Characteristic macrofossils of unit 3, such as the chonetids and Spirifer sp., occur about 10 feet above fossiliferous beds of the Three Forks in the cores from the southern margin of the formation where the lower Bakken shale is either less than about 3 feet thick or is absent (NDGS Well Nos. 7579 in Williams County, and 7887, 8474, and 935 in Billings County); thus the faunas of the Bakken and the Cyrtospirifer fauna of the Three Forks Formation appear to be vertically separated near the margins of the basin.

Special permission was granted to this writer by the NDGS to examine the unpublished core-description data of Lineback and Davidson which contains faunal lists and age assignments for conodonts that they collected from the Bakken black shale members in 13 of the cores used in this study. The ages they assigned to the Bakken black shales on the basis of these conodonts closely match the age determinations of the Bakken black shales made in this study and in the study by Hayes (1984) in all but one of the cores they examined. Much of their physical evidence supporting their conclusion that the Bakken is time-transgressive is based on the assumption in their unpublished data that NDGS Well No. 105 in Ward County represents the lower Bakken shale and the basal few feet of the middle member. Thus their collection of Kinderhookian conodonts from the black shale of this marginal core combined with their collection of upper Devonian conodonts from the lower black shale in cores from near the center of the basin suggested to them that the

Bakken lower shale is of Late Devonian age near the center of the basin and Kinderhookian toward the margins. Other studies of this same marginal core, however, (Webster, 1982; Hayes, 1984; this study) have interpreted this core (NDGS Well No. 105) to represent the upper Bakken shale and the upper few feet of the middle member. This discrepancy is based on the fact that there are two sets of well depths written on the core boxes of this core; one set would indicate that the core represents the bottom part of the Bakken and the other would indicate the top part of the formation. Evidence suggesting that this core represents the upper part of the Bakken includes the presence of fossils typical of the unit 3 fauna, such as Spirifer sp. and the small, distinctive Chonetes gregarius, in the siltstone member of this core and the presence of Kinderhookian conodonts from the black shale of this core reported in the unpublished data of Lineback and Davidson (1982) and by Hayes (1984, 1985).



## SUMMARY OF CONCLUSIONS

1. Well over 500 macrofossils that represent more than 50 taxa were found in well cores of the Bakken Formation from western North Dakota. These were found mostly within five stratigraphic intervals of the Bakken; two of these intervals occur in the lower black shale member and the other three occur in the middle member

2. Each of the five fossiliferous intervals, or biosomes, of the Bakken contains a different assemblage of macrofossils; thus, different associations of organisms occurred in the same vertical sequence from core to core

3. The lowest biosome of the Bakken Formation is a rhynchonellid assemblage found locally within the basal few feet of the lower black shale member. The fauna of this interval is characterized by benthic forms and resembles a Leiorhynchus assemblage that occurs locally near the base of Devonian black shales in the eastern United States. This fauna in the Bakken includes the brachiopods Rugaltarostrum madisonense (formerly called Leiorhynchus madisonense), Barroisella sp., and Lingula sp. 2, several genera of gastropods and pelecypods, a straight cephalopod, a coiled cephalopod, ostracods, and the conchostracan Cyzicus (Lioestheria) sp.. Single valves of the inarticulate brachiopods and C.

Lioestheria) sp. are the most common macrofossils of this lowermost biosome in the Bakken

4. The other fossiliferous interval in the lower member consists of a proliferation of single valves of the conchostracan C. (Lioestheria) sp. within the top few inches of the lower black shale member. These valves

lie flat on bedding planes and mark a persistent biosome within the central portion of the Williston Basin, but seem to be confined to that area, perhaps due to later erosion of this bed. This biosome in the Bakken appears similar faunally, lithologically, and stratigraphically to a conchostracan bed that occurs in the Bakken correlatives in the western United States (the Sappington Member of the Three Forks Formation, the Leatham Formation, and the Leatham Member of the Pilot Shale) and in the Bakken's nearest correlative, the Exshaw Formation in Alberta. The fauna of this conchostracan bed in the Bakken Formation is much less diverse than is the conchostracan bed in the Bakken correlatives or the fauna from near the base of the lower black shale; the only other macrofossil collected from the top few inches of the lower member of the Bakken is the posterior portion of a shrimp-like organism.

5. Outside of these two fossiliferous intervals, macrofossils are rare in the lower black shale; those found consist of one lingulid valve, one small, straight cephalopod, possible ostracods, scattered, disarticulated fish fragments, and two possible plant stems. Also, numerous thalli of Foerstia sp. occur over a short section in one core from near the center of the basin; the presence of this supposed algal form in the basal part of the lower shale member appears to mark a widespread time-stratigraphic horizon of Late Devonian age and suggests a correlation of this interval in the lower shale member with part of the black shale member of the Exshaw Formation and part of many Upper Devonian black shales in the eastern United States, such as the Chattanooga, New Albany, and Ohio Shales.

6. The other three fossiliferous intervals of the Bakken occur in the

middle, predominately siltstone member of the formation. Because these three fossiliferous intervals occur in concert with a tripartite succession seen in the lithology of the middle member, the middle member is here divided into three informal stratigraphic intervals, units 1, 2, and 3 for the lower, middle, and upper intervals, respectively. Units 1 and 3 consist, generally, of massive siltstone or silty limestone that contains abundant brachiopods; unit 2 is a relatively thick, generally unfossiliferous sequence of thin, intercalated beds of shale, siltstone, and sandstone.

7. Unit 1 of the middle member, up to about 30 feet thick, typically comprises the basal 40 percent of the member and is the third fossiliferous interval of the Bakken. This unit contains a Syringothyris brachiopod fauna scattered throughout its matrix that correlates with the fauna of the Louisiana Limestone of latest Devonian age in the upper Mississippi Valley and with the Syringothyris fauna in the siltstone members of the Bakken correlatives in the western United States (the Sappington-Leatham-Leatham Member subcomplex), also of latest Devonian age; ten genera of brachiopods were found in unit 1 and all have been reported from the Louisiana or the Bakken's depositional subcomplex. Nonbrachiopod fossils of unit 1, such as the trace fossils Scalarituba missouriensis and Cosmoraphe sp. and poorly preserved molluscs, also appear similar to elements of the Syringothyris fauna elsewhere.

8. Unit 2 of the middle member, up to about 35 feet thick, typically comprises about 50 percent of the middle member, and has little biostratigraphic control due to a general scarcity of fossils in the thin bedded rocks of the unit. Unit 2 does contain the fourth fossiliferous

interval of the Bakken Formation, however, as abundant blade-like "leaves" form a persistent biosome within the basal few feet of this unit in the central portion of the basin; the lateral extent of this biosome coincides closely with that of the conchostracan bed. These plants appear to correlate with abundant blade-like "leaves" that occur locally in thin-bedded rocks at the base of the type Mississippian section in western Illinois. This correlation, and the correlation of the brachiopods in units 1 and 3, suggest an early Mississippian age for unit 2. The Devonian-Mississippian boundary in North Dakota thus appears to occur in the middle member of the Bakken Formation at the contact between units 1 and 2; this is a poorly defined contact and no evidence of erosion was noted at this juncture

9. Unit 3 of the middle member occupies the top three to ten feet of the Bakken siltstone and is the fifth fossiliferous interval of the Bakken. This unit contains abundant brachiopods that consist mostly of species of Chonetes and Spirifer a total of 16 species of brachiopods that represent 12 genera were found in unit 3. Other fossils of this unit include one minute pygidium of a trilobite and a few disarticulated pelmatozoan columnals. The brachiopods of unit 3 appear to correlate with the McCraney Limestone in the type Mississippian section and with the Spirifer marionensis fauna of the siltstone member of the Exshaw Formation in Alberta, also of early Mississippian age. Although a direct correlation between these two correlative faunas of unit 3 has not, to my knowledge, been previously made, both have been previously correlated with the distinctive Syringothyris fauna of the Louisiana Limestone until physical and conodont evidence demonstrated that the McCraney and the Exshaw siltstone member are of an early, but not earliest, Missis-

sippian age and are thus of a significantly younger age than is the Louisiana. Like the faunas of the McCraney and Exshaw siltstone, the unit 3 fauna also appears similar to the Syringothyris fauna; this was seen in this study by the similarity between the faunas of units 1 and 3 of the middle member, as one-half of the brachiopods from unit were also found in unit 3.

10. The age and stratigraphic relationships of the brachiopod faunas in the Louisiana and McCraney has been controversial not only because of a similarity between the rocks and fossils of these units, but also because the faunas occur close by each other but have never been found in the same stratigraphic section. The presence of correlatives of both the Syringothyris fauna and the McCraney fauna in the Bakken Formation thus appears to represent a unique occurrence of these faunas in the same stratigraphic section; the vertical separation of these faunas in the Bakken in units 1 and 3 appears to demonstrate conclusively the relative ages of the faunas

1. No fossiliferous intervals or age-diagnostic fossils were found in the upper black shale of the Bakken. Macrofossils are rare in this member and consist mostly of small, thin-shelled fossils, such as inarticulate brachiopods and Cyzicus (Lioestheria) sp..

12. Evidence for facies control of the fossils, or time transgression of the units of the Bakken, was not seen in this study. The fauna of unit 3 is the most laterally extensive fossiliferous interval of the Bakken and appears to extend to near the margins of the formation; in the marginal cores, unit 3 and the upper few feet of unit 2 seem to lie directly on the Three Forks Formation of Late Devonian age. The uniform



lithology of the Bakken beds seen from core to core in this study suggests that the limited extent of the conchostracan bed and blade-like leaves is due to intraformational erosion rather than to facies control; thus their occurrence in the central portion of Bakken appears to mark the area in which the Bakken section is most complete. The limited extent of these two thinnest fossiliferous intervals of the Bakken also suggest that the upper beds of the lower black shale member and the lower beds of unit 2 are the first beds of those lithosomes to pinch out toward the margins of the basin.

13. Structural trends suggest that unit 3 of the middle member and the upper black shale member of the Bakken Formation were deposited after a shifting of the alignment of the seaway in the Williston Basin, resulting in poorly-defined depocenters for these lithosomes. Older rocks tend to have well-defined depocenters and are more affected by structural features, such as the Nesson Anticline, than are unit 3 and the upper black shale

14. The black shales of the Bakken generally represent relatively deep water, anaerobic environments with minimal current activity and the middle member appears to represent shallow water, aerobic environments with moderate current activity.

15. The lower black shale of the Bakken appears to have been deposited in a deepening sea during a worldwide rise in sea level and unit 1 of the middle member was deposited during a major regression; unit 2 is the least extensive unit of the Bakken and appears to represent the low stand of the Bakken seas. Unit 2, unit 3, and the upper shale member are transgressive, overlapping deposits; the upper shale member is the

most widespread Bakken member and appears to represent the high stand of the Bakken seas

SYSTEMATIC PALEONTOLOGY

Kingdom ANIMALIA

Phylum COELENTERATA

Class SCYPHOZOA

Subclass CONULATA

Order CONULARIIDA

Suborder CONULARIINA

Family CONULARIIDAE Walcott

Subfamily PARACONULARIINAE Sinclair, 1952

Genus Paraconularia Sinclair,

Type species.--Conularia inaequicostata DeKoninck, 1883 (by original designation).

Diagnosis.--"Transverse ribs moderately strong, faintly tuberculate, abruptly bent adaperturally at their terminations on edges of corner furrows; mid-line on faces indicated only by slight deflection of ribs along it" (Moore and Harrington, 1956, p. F65)

Discussion.--Moore and Harrington (1956, p. F65) indicated that Paraconularia is the only genus of this subfamily to occur in the lower Kinderhookian.

?Paraconularia missouriensis (Swallow, 1860)

Pl. 2, fig. 4

Diagnosis.--"Very large, elongated, four-sided, pyramidal with two opposite sides wider than other two; cross-section triangular angles at four corners deeply furrowed longitudinally; sides without distinct median groove" (Shimer and Shrock, 1944, p. 77-79).

Discussion.--One small fragment of two conulariid faces and an



interfacial groove show the characteristic features of the subfamily in that the transverse ridges of the faces are interrupted, are sharply inflected inward at the corner, and occur in an alternating pattern at the interfacial groove. The transverse ridges are of a very small size and, along with the general proportions of the specimen, suggest that the specimen represents a small-sized conulariid or an area near the apex of Paraconularia missouriensis, a widespread Kinderhookian species. The specimen has about five transverse ridges in the space of a millimetre, is about .3 mm high, as measured along the interfacial groove, and one of the conulariid faces is about 2.0 mm wide and the other is about 1.0 mm wide.

Material and Occurrence.-- The specimen was collected by Kume (1963) from what he considered to be the upper black shale member of the Bakken Formation in NDGS Well No. 207 in Wells County. This core might not represent the Bakken Formation, however, as Bjorlie (1979, p. 45) considered it to represent the Carrington shale facies of the Lodgepole Formation and Webster (1982, p. 22) indicated that the Bakken does not extend as far east as the locality of NDGS Well No. 207. This core, consisting of medium- to dark-gray siliceous shale, was re-examined for other fossils in this study without success.

Class ANTHOZOA

Subclass TABULATA

Order AULOPORIDA

Superfamily SYRINGOPORICAE de Fromentel, 1861

Family Syringoporidae de Fromentel, 186

Genus Syringopora Goldfuss, 1826

Type Species.--S. ramulosa Milne-Edwards and Haime, 1850 (by

subsequent designation of Milne-Edwards and Haime, 1850, p. 62).

Diagnosis.--"Corallum fasciculate; corallites cylindrical, moderately thick-walled, connected by tubuli without regularity of orientation; septa represented by longitudinal rows of spinules or ?absent; tabulae infundibuliform, forming axial syrx in many corallites; increase lateral or from connecting tubuli" (Hill, 1981, p. F647).

Syringopora sp. morphogroup C of Sando, 1984

Pl. 2, fig. 14

Diagnosis.--Famennian and Kinderhookian syringoporids from the Western Interior region with a corallite diameter of 2.7 to 3.3 mm and a corallite density of 3 to 10 corallites per square centimeter (Sando, 1984, p. -3).

Discussion.--This form is represented by one specimen from the middle member that consists of three fasciculate, cylindrical corallites connected by tubuli. The corallum is partly crushed and broken as the fragmental corallites are, in places, tightly pressed against each other and the tubuli are fractured and separated. The infundibular tabulae, lines of septal spikes, and syrx are visible but further details of the interior were not seen because the single specimen was not thin-sectioned. The corallites are 10 to 14 mm long and have a diameter of 2.7 to 3.0 mm. The size and distribution of corallites suggests that the specimen be placed in Sando's morphogroup C.

Sando (1984) divided the late Devonian and Mississippian syringoporids of the Western Interior into seven morphogroups (A through G) on the basis of corallite diameter and to a lesser extent on corallite density. Sando noted (p. that these morphogroups "are tentative taxonomic groupings based on somewhat arbitrary and convenient morphologic

criteria", and reported further that "these groupings may be species or species groups and need to be tested by statistical studies

Sando 1984) also reported that morphogroups A through D occur in the Williston Basin of North Dakota and that they date back to the upper Famennian Polygnathus styriacus zone

Materials and Occurrence.--The specimen was collected by Hayes 1984) from a formic acid bath of a core piece from near the middle of the middle member in the basal part of 2), which is a horizon where fossils were rarely found. The coral is from a roughly one-inch-thick bed of light gray, coarsely crystalline limestone intercalated in a three-foot core section of interbedded dark gray dolomitic siltstone and calcareous siltstone in NDGS Well No. 527. Also occurring on this core piece is the interarea of a pedicle valve of Spirifer sp..

Phylum BRACHIOPODA

Class INARTICULATA

Order LINGULIDA

Superfamily LINGULACEA Menke, 1828

Family Lingulidae Menke

Genus Lingula Bruguière

Type Species.--L. anatina Lamarck 1801, p. 14 ICZN pending).

Diagnosis.--"Elongate, lateral margins gently convex to subparallel, ornament only of concentric growth lines; shell thin, slightly thickened in areas of muscle attachment. Internally without septa, low median ridge in brachial valve may be present extending from central scars to anterior lateral scars" (Rowell, 1965, p. H263).

Lingula sp. 1

Pl. 1, fig. 2

Discussion.--This is a small, spatulate Lingula that is preserved as dark, shiny, carbonaceous impressions with well preserved concentric growth lines that number more than 20 per millimetre. The shells appear similar to L. spatulata Hall; Hall (1867, p. 13) said of this species that "this little shell, without any conspicuous features, is usually recognized without difficulty by its small spatulate form." The scarcity and fragmental condition of the Bakken material, however, prevents a more definite comparison with Hall's Upper Devonian (Frasnian) species from New York. All except one of the specimens are smaller than Hall's specimens; the largest (No. 5088.44) is 3 mm wide and 5.5 mm long, and the smaller ones are all of about the same size, with the most complete one being .6 mm wide and 2.8 mm long.

Material and Occurrence.--A total of five disarticulated valves were found from within a foot of each other near the top of the upper black shale in NDGS Well No.

Lingula sp. 2

Discussion.--This is a locally common form from near the base of the lower black shale that appears similar to Lingula sp. 1 but has more parallel lateral margins than that species. Externally, the specimens more closely resemble L. ligea Hall, which Girty 1939, p. 53) reported can be indistinguishable from L. spatulata, which, as mentioned, is the species that Lingula species most closely resembles. The specimens are typically about 3.0 mm wide and 6.0 mm long. There seems to be some variability in the shape of the shell, as some appear slightly oval, with a width of up to 4.2 mm and a length of about 7.0

mm

Material and Occurrence.--This small lingulid is from within the basal few feet of the lower shale member. Occurrences of this species were noted in NDGS Well Nos. 607, 2383, and 5088.

Lingula sp. 3

Pl. , fig. 5

Discussion.--This form is represented by one very incomplete valve (5088.10) obtained by Hayes (1984) from bleaching a core piece taken from the lower black shale. It differs from the other Bakken lingulids chiefly by its much greater width, which, if reconstructed, would be more than 10 mm, and the shell would have a nearly circular outline. The shell is thin and appears somewhat similar to that of L. exilis Hall except that the latter species was said (Hall, 1867, p. 7) to have its greatest width at the apex. Only the beak area and the posterolateral margins are preserved, but these show a width of about 9.5 mm. Fine concentric growth lines average about 10 per millimetre on the posterolateral slopes and are not present in the beak

Material and Occurrence.--The specimen is from the lower one-half of the lower black shale in NDGS Well No. 5088

Lingula sp. 4

Pl. 1. fig. 1

Discussion.--This species is represented by two specimens from the middle member; one specimen, from unit , consists of two articulated valves slipped slightly past each other and the other, from unit 3, is the beak area of one disarticulated valve. External ornamentation consists of concentric growth lines that average about six per millime-

tre; the growth lines on the articulated specimen are crowded at intervals that form ridges similar to those of L. krugeri of the Louisiana Limestone (Williams, 1943, p. 68). The shape of this specimen is also similar to that of L. krugeri, but the specimen at hand is smaller and has much coarser growth lines than does that species; it more closely matches the dimensions of L. melie Hall (Hall, 1867, pl. 1, fig. 3, 4), but the Bakken specimen has a much coarser ornamentation and a more undulated surface than that species. The Bakken specimens are stained light brown and some of the growth lines on the specimen from unit 1 have a bluish tint due to the phosphatic material of the shell. The most complete valve of the articulated specimen is 6.4 mm wide and 8.3 mm long; the other valve of this specimen shows the anterior portion of a featureless interior and, like the specimen from unit 3, is too incomplete for measurement

Material and Occurrence.--The articulated specimen is from about three feet below the top of unit 1 of the middle member in NDGS Well No. 8069 and the other specimen is from near the top of unit 3 (near the top of the middle member) in NDGS Well No. 4958

Genus Barroisella Hall and Clarke, 1892

Type Species.--B. campbelli Cooper, 1942, p. 228 (nom. subst. pro Lingula subspatulata Meek and Worthen, 1868, p. 437; by original designation)

Diagnosis.--"Elongate oval in outline, ornament of concentric growth lines; brachial valve with low broad median ridge, bifurcating near middle of valve, between bifurcation second low ridge intercalated, probably bearing anterior lateral scars" (Rowell, 1965, p. H263).

Barroisella sp.

Pl. 1, figs. 8, 9

Discussion.--This is a locally abundant form from the lower black shale that is assigned to a species within Barroisella because of the bifurcating median ridge that is commonly seen as furrows in molds of the interior. The septa are generally well preserved and well exposed, as the shell material is very thin and sometimes translucent and easily removed. The low, median ridge, intercalated between the anteriorly bifurcating ridges, is also commonly visible but other internal features, such as the muscle scars, could not be seen. A specific assignment is not made here because the material is crushed and fragmented. Large specimens are typically about 3 mm wide and 6 mm long; shells may be as small as about 1 mm wide and 3 mm long.

Material and Occurrence.--The shells were found in the bottom few feet of the lower black shale in NDGS Well Nos. 527, 607, 2383, and 4264. The shells are moderately well preserved, locally abundant, and form a lag deposit on one bedding plane (No. 2383.10). There they are associated with Lingula sp. 2, conodonts, scattered unidentifiable spinules up to about one millimetre long, and what appears to be a compressed hyolithid fragment about 8.5 mm long and tapers from 3.0 mm to 2.2 mm.

## Order ACROTRETIDA

## Suborder ACROTRETIDINA

## Superfamily DISCINACEA Gray, 1840

## Family Discinidae Gray,

## Subfamily Orbiculoideinae Schuchert and LeVene, 1929

Genus Orbiculoidea d'Orbigny, 1847

Type Species.--Orbicula forbesi Davidson, 1848, p. 334 (ICZN pending).

Diagnosis.--"Concentric ornament of both valves varying from fine growth lines to well-defined fila; brachial valve conical to subconical . . . pedicle valve subconical to gently concave, pedicle track narrow, closed anteriorly by listrium . . ." (Rowell, 1965, p. H285).

Orbiculoidea limata Rowley, 1908

Pl. 1, figs. 6 7

Orbiculoidea limata Rowley, 1908, p. 72, pl. 17, figs. 1, 2; Williams, 1943, p. 68-69, pl. 6, fig. 53.

Diagnosis.--"Distinguishing characters [of the brachial valve] are its small size, subcircular shape, relatively high convexity, prominent beak, which is one-third the length of the shell from the posterior margin, and steeply sloping convex area extending from the beak posteriorly."; pedicle valve unknown (Williams, 1943, p. 69).

Discussion.--This is an uncommon form from units 1 and 3 of the middle member and the upper shale member that is assigned to this genus and species largely on the basis of its small size, nearly circular shape, concentric and holoperipheral growth lines, position of the beak, non-calcareous shell material, and the presence of a pedicle track. The Bakken brachial valves are similar in size, shape, and ornamentation to brachial valves from the Louisiana Limestone that were assigned to this species by Rowley (1908) and Williams (1943) and to forms from the top of the lower black shale (unit C) of the Sappington that were reported by Rodriguez and Gutschick (1967, p. 369) to be suggestive of O. limata they assigned their specimens instead to an undet-



ermined species of Orbiculoidea "because of the possible shell distortion and lack of a pedicle valve in the collections." A single pedicle valve from unit of the middle member (Pl. 1, fig. 7) has a foramen that extends from the apex to about three-fourths of the length of the shell toward the posterior margin and has a nearly centrally located apex. The brachial valves have their apex located about one-third of the length of the valve from the posterior margin, which agrees with Williams' (1943, p. 69) diagnosis of the species and with the characterization of the genus by Weller (1914, p. 43), who distinguished brachial valves of Orbiculoidea from those of Crania by Crania's "more nearly central position of the apex and its more erect position". The Bakken brachial valves are mostly flattened, but appear to have a slightly to a, more rarely, strongly posteriorly inclined beak. Only the smallest specimen from the middle member appears to have its original conical shape preserved, as it has a relatively high convexity of about 1 mm with a steep slope from the apex toward the posterior margin.

The Bakken orbiculoids are molds of the exterior, and those from the middle member are stained light to medium brown and some have a bluish tint; some specimens are partly replaced by pyrite. The specimens from the upper shale member are three very small brachial valves that are black and shiny or partly replaced by pyrite. The thinness of the shell of this species (as mentioned by Rowley, 1908, p. 72) is seen on one core piece from the middle member, where one valve is slightly distorted by its being pressed against two productoid spines and another has been pressed against a costate brachiopod fragment resulting in the valve taking on the shape of that fragment. The largest specimen found is the pedicle valve which is nearly flat and 8 mm wide and 7.5 mm long.

The largest brachial valve is 6 mm wide and 7.5 mm long; other brachial valves from the middle member range in size down to one that is about 3 mm wide and 3 mm long. The specimens from the upper shale member are about 2.5 mm wide and 2.2 mm long

Material and Occurrence.--Of the 11 specimens found, five (including the pedicle valve) are from unit 1 of the middle member in NDGS Well Nos. 4958 and 8069, three are from unit 3 in NDGS Well Nos 5088, 7887, and 8069, and the three smallest ones occur over about an one-half-inch-thick interval near the middle of the upper shale member in NDGS Well No. 607; this interval also contains conchostracans and the only gastropod and pelmatozoan columnals found in the upper black shale. If indeed all of the Bakken specimens belong to this species, this is then the first report of this Late Devonian species in early Mississippian rocks.

#### Class ARTICULATA

#### Order ORTHIDA

#### Superfamily ENTELETACEA Waagen, 1884

#### Family Rhipidomellidae Schuchert, 1913

#### Genus Rhipidomella Oehlert,

Type Species.--Terebratula michelini LeVeillé, 1835, p. 39 (by original designation).

Diagnosis.--Shell outline subcircular to subovate, dorsibiconvex, and sublenticular. Hingeline short and interarea narrow; pedicle valve with better developed interarea than brachial valve and with two strong hinge teeth; hinge teeth supported by usually well-defined and curved dental lamellae that extend anteriorly and border a large and subovate muscle field. Brachial valve with large and bilobed cardinal

process, deep and narrow sockets, and prominent socket plates that, in some cases, support short crura; brachial valve muscle area small, quadripartite, usually indistinct. Surface of both valves marked by rounded, subequal costellae that radiate from the beak (modified from Weller, 1914, p. 147).

Rhipidomella missouriensis (Swallow, 1860)

Pl. , figs. 14-18

Orthis missouriensis Swallow, 1860, p. 639; Hall and Clarke, 1892, pl 6A, figs. 16, 17.

Rhipidomella missouriensis (Swallow). Weller, 1898, p. 524; Rowley, 1908, p. 78, pl. 17, figs. 43-47; Weller, 1914, p. 148, pl. 20, figs. 1-8; Branson, 1938, p. 42-43, pl. 5, figs. 25-27; Williams, 1943, p. 72, pl. 6, figs. 55-66; Brown, 1952, p. 85; Hyde, 1953, p. 220-222, pl. 6, figs. 17-30; Brindle, 1960, p. 88, pl. 20, figs. 10- ; Rodriguez, 1961, p. 60-61, pl. 3, figs. 4, 5; Rodriguez and Gutschick, 1967, p. 369-370, pl. 41, figs. 14-21, 28, 29.

Diagnosis.--A nearly circular, small- to medium-sized early Mississippian Rhipidomella with strong, radiating costellae; hingeline width less than half of maximum width; usually wider than long. Pedicle valve beak small and inconspicuous, a little extended beyond hingeline. Sulcus in brachial valve reduced or absent (modified from Rodriguez and Gutschick, 1967, p. 369; and Williams, 1943, p. 72)

Discussion.--This is a common and distinctive form of the middle member that closely resembles the illustrations and descriptions of this latest Devonian to early Mississippian species. The shells are of medium size for the species, or a little larger; most are disarticulated

and crushed, and many are decorticated. Pedicle valves generally have a well-developed beak and, because of the internal support from the dental lamellae, an uncrushed umbo. Interiors of pedicle valves were not seen. Brachial valve interiors (Pl. 1, figs. 16, 7) have short, widely diverging socket plates and a short, thick median ridge; muscle scars were not seen. Interareas were not seen. Both valves are covered by fine costellae or coarse capillae that number about three per millimetre and are crossed at intervals by concentric growth lines that become more abundant toward the anterior margin. Two typical specimens are 23.4 and 25.3 mm wide, and 21.1 and 22.3 mm long, respectively. The largest specimen is a nearly complete valve that is 29.7 mm wide and 27 mm long, although the posterior margin is missing. The strong concentric growth lines of R. missouriensis give this largest specimen a rugose appearance, a feature Rowley (1908, p. 79) reported in gerontic specimens from the Louisiana Limestone. Several immature shells were also found. These were identified by their characteristic rounded outline and coarse capillae that bifurcate near the anterior margin at about the same distance from the apex as do costellae on the larger specimens. The smallest of these immature shells is about 8 mm wide and 7 mm

Material and Occurrence.---Approximately 70 valves were either collected or noted in the middle member; most are from unit 1 and six were found in unit 3. The specimens from unit 1 were found in NDGS Well Nos. 607, 999, 1405, 2967, 3167, 4340, 4508, 4958, 5088, 7851, 8069, and 8177; those from unit 3 are from NDGS Well Nos. 7887, 8069 and 9351. In addition, two nearly complete, heavily pyritized valves were found on one bedding plane from within the bottom couple of inches of the upper shale in NDGS Well No. 5088. There is evidence that these

were reworked shells, however, as indicated by their proximity to the middle member and especially by their occurrence with an equally heavily-pyritized, fossil-fragment hash on the same bedding plane.

#### Order STROPHOMENIDA

##### Suborder STROPHOMENIDINA

Superfamily DAVIDSONIACEA King, 1850

Family Meekellidae Stehli, 1954

Subfamily Meekellinae Stehli, 1954

Genus Schellweinella Thomas, 1910

Type Species.--Spirifera crenistria Phillips, 1836, pl. 9,  
6 (by original designation)

Diagnosis.--"Biconvex to resupinate, pedicle valve commonly less convex than brachial valve and distorted umbonally due to cementa-costellate; pseudodeltidium well developed, chilidium obsolescent; dental plates short, reaching to floor of pedicle valve; cardinal process low with discrete lobes" (Muir-Wood and Williams, 1965, p. H407).

Discussion.--Schuchertella is difficult, if not impossible, to distinguish from Schellweinella. Weller (1914, p. 59) reported that these two genera are closely related, and Williams (1943, p. 72) reported that "some forms of Schuchertella resemble Schellweinella because there are gradations between the rudimentary dental plates of Schuchertella and the short dental plates of Schellweinella." The classification of these forms is still problematical; Cooper and Dutro (1982, p. 54) wrote, "the American 'schuchertellas', as indeed all the related forms, are in great need of revision."

Schellweinella inflata (White and Whitfield, 1862)

Pl. 1, fig. 20

Streptorhynchus inflatus White and Whitfield, 1862, p. 293; Hall and Whitfield, 1877, p. 253, pl. 4, fig. 3.

Orthothetes inflatus (White and Whitfield). Hall and Clarke, 1892, pl. 9A, figs. 24, 25; Weller, 1901, p. 181, 195, pl. 16, figs. 2, 3, pl. 19, figs. 10-12.

Schellwienella inflata (White and Whitfield). Weller, 1914, p. 59, pl. 4 figs. 7-12, pl. 83, fig. 11; Branson, 1938, p. 162, pl. 17, figs. 13, 14; Hyde, 1953, p. 226, pl. 8, figs. 22-28; Rodriguez and Gutschick, 1967, p. 370-372, pl. 41, figs. 22-26.

Diagnosis.--"A medium to large Kinderhookian species of Schellweinella lacking a sulcus and having a strongly convex brachial valve bearing a prominent umbo and obtusely angular cardinal extremities" (Rodriguez and Gutschick, 1967, p. 371).

Discussion.--This is an uncommon form from unit 1 of the middle member that is recognized by the large size, coarse capillae, subrounded outline, convexity, and lack of strong concentric growth lines. A nearly planar fragment of a pedicle valve and four moderately convex brachial valves were found. The shells are incomplete but are generally well preserved molds of the exterior with about three capillae per millimetre. Growth lines are generally absent, although one or two somewhat inconspicuous and rugosic growth lines are present on two of the brachial valves. The specimens are larger than the Bakken specimens assigned to Schuchertella lens and, although the largest Rhipidomella missouriensis is of a comparable size, that species has strong concen-

tric growth lines, a narrower hingeline, and a more circular anterior outline. Fragments of these species are difficult to distinguish because of their similar surface ornamentation. The specimens are of about the same size or slightly larger than specimens from the Sappington assigned to this species by Rodriguez and Gutschick (1967), who reported (p. 371) that theirs are a little large for the species. The Bakken material is also similar to a specimen from Early Mississippian rocks in Missouri illustrated by Branson (1938). The largest specimen from the Bakken is about 37 mm wide (as determined from its half-width) and 29 mm long.

Material and Occurrence.--Five specimens were found in unit of the middle member in NDGS Well Nos. 1405, 2967, 4508, and 4958.

Family Schuchertellidae Williams, 1953

Subfamily Schuchertellinae Williams, 1953

Genus Schuchertella Girty, 1904

Type Species.--Streptorhynchus lens White, 1862, p. 28 (by original designation).

Diagnosis.--"Plano-convex to biconvex, costellate, with costellae added by intercalation during shell growth; dorsal interarea linear; cardinal process lobes low, not united posteromedianly; median ridge dividing dorsal adductor field variably developed; shell substance impunctate" (Williams, 1965, p. H408).

Discussion.--Williams (1943, p. 72) reported that "the distinctive characters [of Schuchertella] consist of a combination of the relatively fine radial ornamentation of the exterior of the valves and the rudimentary or incompletely developed dental plates and lack of a medium septum of the interior of the ventral valve." These characters,

however, do not suffice to distinguish it from Streptorhynchus King. Williams reported that Schuchertella typically has a wider shell with a much lower interarea than Streptorhynchus but that there are intermediate forms between the two. No forms which should be allied with Streptorhynchus were found in the Bakken Formation, since all the schuchertellid brachiopods found have low pedicle interareas.

Schuchertella lens (White, 1862)

1, fig. 19

Streptorhynchus lens White, 1862, p. 28; Keyes, 1894, p. 67, pl. 39  
figs. 2a, 2b

Orthothetes lens (White). Hall and Clark, 1892, pl. 11A, figs. 16-22  
pl. 16, figs. 12-16, Rowley, 1908, p. 78, pl. 17, figs. 37-42

Schuchertella lens (White). Girty, 1904, p. 734; Weller, 1914, p. 55,  
pl. 3, figs. 1-8, 9?; Branson, 1938, p. 162, pl. 17, figs. 13, 14; Williams, 1943, p. 72-73, pl. 7, figs. 1-7 (further synonymy); Rodriguez and Gutschick, 1967, p. 370, pl. 44, figs. 15-20, 29, 31-34.

Diagnosis.--A small to medium-sized Schuchertella slightly wider than long, bearing strong, uniform, radiating capillae which average about three per millimetre and are separated by narrow furrows (modified from Rodriguez and Gutschick, 1967, p. 370; and Williams, 1943, p. 73).

Discussion.--This is an uncommon form from unit of the middle member that is recognized largely by its external features, as few internal structures were seen and the specimens match the external characteristics of the species as described by Weller (1914 and Williams (1943). The shells are disarticulated and are mostly preserved as



slightly decorticated molds of the exterior with well preserved coarse capillae that number about three per millimetre; two specimens are molds of the interior with less well preserved capillae. The pedicle valves are moderately to weakly convex and brachial valves are weakly convex to nearly planar, making the valves difficult to distinguish from each other. The interior of a low, flat, and apsaclinic interarea was seen on one brachial valve. This interarea is partly embedded in the matrix and the cardinal process is broken away but appears to be similar to the interarea of the species as described by Weller (1914). The shells have a relatively large variation in their dimensions but are within the size range of the species (Weller, 1914). Complete specimens range in size from a pedicle valve measuring 20.6 mm wide and 14.1 mm long, to a brachial valve 9.1 mm wide and 6.4 mm long.

One very small specimen from unit of the middle member appears similar to juvenile forms of S. lens illustrated by Rodríguez and Gutschick (1967, pl. 44, figs. 15-20), and both the Bakken and Sappington forms appear similar to a form from the Louisiana Limestone named S. louisianensis by Williams (1943, p. 73). He noted (p. 74) that his specimens might represent immature S. lens, but he decided to erect a new species for them since no specimens were found to be transitional between this species and S. lens in the Louisiana Limestone. Rodríguez and Gutschick (1967, p. 370) considered their specimens to be immature forms of S. lens due mostly to their larger size (up to 6 mm wide), and higher, more variably inclined interareas than those of S. louisianensis. The fact that the interarea of the Bakken specimen is also not quite cataclitic and the fact that the valve is slightly larger than those from the Louisiana Limestone prevents its assignment to S. louis-

sianensis. The fact that both the Bakken and the Sappington specimens appear to be transitional between S. lens and S. louisianensis suggests the possibility that these forms may, in fact, be conspecific. If that is the case, the name S. lens is the senior synonym and should be the name retained. This small Bakken specimen has about eight capillae per millimetre and a high, nearly cataclitic interarea with a highly arched deltidium about twice as high as wide; it has a convexity of about 1 mm and its highest point is just in front of the beak. The shell is 3.1 mm wide and 2.3 mm long.

Material and Occurrence.--Ten specimens, including the possible juvenile form, are from unit of the middle member and were found in NDGS Well Nos. 3167, 4340, and 8069. Six molds of the exterior were found on the same bedding plane near the top of unit in NDGS Well No this is normally a rare stratigraphic horizon for the occurrence of microfossils in abundance.

#### Suborder CHONETIDINA

Superfamily CHONETACEA Bronn, 1862

Family Chonetidae Bronn, 1862

Subfamily Chonetinae Bronn, 1862

Genus Chonetes Fischer de Waldheim, 1830

Type Species.--Terebratulites sarcinulatus von Schlotheim p. 256 (by subsequent designation of de Verneuil, 1845, p. 240).

Diagnosis.--"Shell small, semicircular; valves plano- or slightly concavo-convex; interareas narrow; pseudodeltidium present; hinge equal to or slightly less than greatest width of shell; shell surface with fine bifurcating capillae . . . spinules rare or absent.

Interior of pedicle valve with strong median septum about half to

two-thirds shell length and enlarged posteriorly; hinge teeth small; two curved ridges diverging from hinge. Interior of brachial valve with bilobed or quadrilobed cardinal process with alveolus; . . . two or more long fine diverging septa but ill-defined median septum, short lateral septa often developed; muscle scars obscure; inner shell surface with radial rows of fine papillae; radial ornament round shell margin" (Muir-Wood, 1962, p. 35-36).

Discussion.--Two species of Chonetes were found in this study and both have an unusual ornamentation for this genus by having fine concentric growth lines on the capillae but not in the intervening furrows. Such an ornament is more characteristic of Retichonetes and perhaps the two species found in the Bakken would be best assigned to that genus (Muir-Wood, 1962; Rodriguez and Gutschick, 1967, p. 372). Muir-Wood 1962, p. 63) reported that Chonetes differs from Retichonetes externally by having less reticulate ornamentation, a less convex pedicle valve, and less well-defined interareas, and internally by having a longer, more anteriorly placed median septum in the pedicle valve and two long lateral septa with a posteriorly located median septum in the brachial valve. The internal structures of the Bakken chonetids are poorly preserved or absent but the external features of the specimens are fairly well preserved and more closely match those of Chonetes than Retichonetes.

Chonetes gregarius Weller, 1901

Pl. 1, figs. 27, 28, 30, 31, 34

Chonetes gregarius Weller, 1901, p. 149-150, pl. 12, fig. 2; Weller, 1914, p. 91-92, pl. 18, figs. 71-72; Brindle, 1960, p. 82, pl. 17, fig.

4

Diagnosis.--Shell small, concavo-convex, length about four-fifths of width, hingeline usually slightly shorter than maximum width, cardinal extremities slightly rounded, and both valves with well developed pseudopunctae. Surface of both valves covered with capillae, which average about eight per millimetre and increase by intercalation and bifurcation; capillae well developed in umbonal area, appearing crenulate throughout their length due to very fine concentric lines which average about ten per millimetre but which are absent in the intercapillate furrows (modified from Weller, 1914, p. 9

Discussion.--Shells with the above characteristics are one of the most common fossils of the middle member and are apparently restricted to its upper few feet where single valves are, in places, concentrated in beds up to a few inches thick. The shells are fairly well preserved as decorticated exteriors and partial molds of the interior. Articulated shells were not found but the valves are generally complete and seemly little abraded.

The decorticated shells are characterized by taleolae (=pseudopunctae) and the fine capillae, which average about eight per millimetre and are crossed by pronounced but fine concentric lines that make the ridges appear crenulate but do not occur in the furrows between capillae. In molds of the exterior, the concentric lines, of course, appear in the furrows. Although several hinge lines were tolerably well

preserved, teeth, sockets, and spines along the hinge were not seen; very small and dissociated spines collected from hydrochloric acid baths of nearby matrix may have belonged to the chonetids. Shells are of typical size for the species and average about 7 mm wide and 5 mm long; the pedicle valve has a convexity of about 1 mm, and the brachial valve is plane to slightly concave.

Several partial internal molds of the pedicle valve show a large flabellate muscle scar that is relatively deeply impressed into the shell. This muscle scar is raised (on the molds) and is seen to be less pustulose than the remainder of the interior with the pustules representing pits in the floor of the valve. This muscle field is bounded posteriorly, not by the ridges (shown by Muir-Wood, 1962, p. 36, 62, for Chonetes and Retichonetes) but seemingly by regions of elevated shell (probably secondary shell thickening) toward the posterolateral margins of the field. A very low, short, median septum occurs in the posterior portion of the muscle field of the pedicle valve

Internal molds of the brachial valves commonly show the taleolae extending as radial rows of papillae that become more common toward the anterior and lateral margins (Pl. 1, fig. 28). No lateral or accessory septa were found in molds of the interior of the brachial valve. The base of the cardinal process, displaying an alveolus, was seen in one or two valves and it seemed to be bilobed but the posterior extremities were not preserved or were covered by matrix.

Comparison.--C. gregarius is a common species in the lower Kinderhookian beds of the Upper Mississippi Valley, but has not been reported from western correlatives of the Bakken. Weller 1914, p. 92-93) reported that C. gregarius is similar in size and shape to C.

geniculatus White from the Louisiana Limestone, and Williams 1943, p. 74) reported that C. gregarius is "the Mississippian species that resembles C. geniculatus the most." Weller 1914, p. 92) reported that C. gregarius differs, most conspicuously, from C. geniculatus by possession of much finer capillae; the capillae of C. geniculatus average about four or five per millimetre and are absent in the umbonal area. C. gregarius may also be distinguished from C. geniculatus by the absence of the concentric lines in the furrows, the less convex pedicle valve, less concave brachial valve, and the less elliptical outline of C. gregarius. The surface ornamentation of C. gregarius is similar to that of C. ornatus, a species which occurs with C. gregarius in unit 3 of the Bakken. These two species differ most conspicuously by the much finer capillae of C. gregarius (Pl. 1, figs. 27, 34)

Material and Occurrence.---This species was found entirely within unit 3 of the middle member in NDGS Well Nos. 105, 3167, 4508 4958, 5088, 7851, 7887, 8069, 8177, and 9351.

Chonetes ornatus Shumard, 1855

Pl. 1, figs. 27, 29, 34

Chonetes ornata Shumard 1855, p. 202, pl. C, figs. 1a-1c

Chonetes ornatus Shumard. Girty, 1899, p. 527-528, pl. 68, figs. 4a-d; Rowley, 1908, p. 75-76, pl. 17, figs. 20-23; Weller, 1914, p. 86-87, pl. 8, figs. 21-29; Branson, 1938, p. 132-133, pl. 16, fig. 14; Williams, 1943, p. 75, pl. 7, figs. 12-19.

Chonetes? ornatus Shumard. Rodriguez and Gutschick, 1967, p. 372, pl. 41, figs. 27.

Diagnosis.---Shell semielliptical, wider than long, greatest

width usually along hingeline; cardinal extremities angular. Pedicle valve moderately convex; brachial valve moderately concave. Surface coarsely capillate, averaging from two and one-half to three capillae per millimetre; concentric markings absent in the furrows (modified from Weller, 1914, p. 86-87).

Discussion.--This species is much rarer than is C. gregarius in the Bakken Formation and is found in association with that species in the upper few feet of the middle member. The shells are generally disarticulated but are well preserved molds of the exterior or partial molds of the interior that closely match the external characteristics of the species. The specimens are of about the same size as the smaller specimens of C. ornatus from the Louisiana Limestone (Williams, 1943, p. 75) and appear similar to a specimen illustrated by Branson (1938) from the Horton Creek Member (Glen Park Member) of the Hannibal Formation in Missouri. The Bakken specimens are strongly multicapillate with distinct capillae that bifurcate and average about three per millimetre at the anterior margin; like C. gregarius, the capillae are crossed by numerous concentric lines that, in molds, appear in the furrows rather than on the ridges. Interareas were too low to be seen. The specimens have an average width of about 7 mm and length of about 5 mm

Comparison.--Weller 1914, p. 86-87) reported that the surface of C. ornatus is similar to that of Retichonetes logani, which has an unusually narrow interarea for a species of Retichonetes, but C. ornatus can be distinguished from R. logani by the somewhat larger size, better developed auricles, slightly coarser and more elevated capillae, and relatively less strongly convex pedicle valve of the former. Williams (1943, p. 75) commented, however, that the slight differences in the

coarseness of the capillae and in the convexity may be of less than specific rank. Muir-Wood (1962, p. 36) and Rodriguez and Gutschick (1967, p. 372) questioned the placement of C. ornatus in Chonetes s.s. since the external features of this species are more typical of species assigned to Retichonetes. Based entirely on external features, Rodriguez and Gutschick assigned the chonetids of the Sappington to C. ornatus but noted that their specimens closely resemble R. logani they could not determine if their specimens should be placed into Retichonetes due to a lack of visible internal structures. The internal structures have not been seen in the Bakken specimens either, and thus it may be that these specimens might also be more properly assigned to a species of Retichonetes.

Weller 1914, p. 88) reported that C. ornatus differs from C. glenparkensis Weller (subsequently assigned by Muir-Wood, 1962, p. 82, to Pliochonetes) by having a less convex pedicle valve, a less concave brachial valve, and a less extended hingeline with consequent less developed auricles. Williams 1943, p. 75), however, had documented an almost complete gradation of these features in the two species and thus reduced C. glenparkensis to varietal status under C. ornatus. This observation led Rodriguez and Gutschick 1967, p. 372) to question the assignment of these species to different genera by Muir-Wood (1962). These external features are variable in the Bakken specimens as well, as one specimen has an extended hingeline with well developed auricles, and thus it is possible that this specimen might be more properly assigned to P. glenparkensis if that species is valid.

Material and Occurrence.--Nine specimens, most of which appear to be pedicle valves, were found in unit 3 of the middle member in NDGS



Well Nos. 105, 4958, 5088, 8069, and 9351. In addition, five poorly preserved and very small juveniles, the largest of which is about 4.0 mm wide and 3.0 mm long, are tentatively assigned to this species largely on the basis of their relatively coarse capillae and the presence of taleolae on molds of the interior. One of the juvenile specimens is from near the base of unit 1 in NDGS Well No. 5088, one is from unit 3 in NDGS Well No. 413, and the other three are from near the top of the upper black shale in NDGS Well No. 5088.

Subfamily Rugosochonetinae Muir-Wood, 1962

Genus Rugosochonetes Sokolskaya, 1950

Type Species.--Orthis hardensis Phillips, 1841, p. 138 (by original designation)

Diagnosis.--Shell small, plano-convex to slightly concavo-convex; greatest width at or near hingeline; interarea low. Shell capillate, averaging about 5 capillae per millimetre, with many bifurcations and few intercalations; growth lines and spinule apertures numerous (modified from Muir-Wood, 1962, p. 65-67).

Rugosochonetes sp.

Pl. 1, fig. 24

Discussion.--One brachial valve from the middle member is assigned to an indeterminate species of Rugosochonetes on the basis of its planar shape, quadrate outline, number of capillae (five to six per millimetre), the minute (about 10 per millimetre) nearly obsolete, concentric lines that occur both on the capillae and in the furrows, and the larger size 10 mm wide and 7 mm long) as compared to the other Bakken chonetids. Small areas of the shell are well preserved but most

of the shell is heavily decorticated; thus the capillae are obscured and the concentric lines are largely removed over most of the shell. Rugosochonetes is found in the lower to upper Mississippian rocks in the Mississippi Valley region, but no species of it have been reported from the rocks of the Bakken's depositional complex or from the Louisiana Limestone

Material and Occurrence.--The specimen is from unit 3 of the middle member in NDGS Well No. 8069

#### Suborder PRODUCTIDINA

#### Superfamily PRODUCTACEA Gray, 1840

#### Family Productellidae Schuchert and LeVene, 1929

#### Subfamily Productellinae Schuchert and LeVene, 1929

#### Genus Orbinaria Muir-Wood and Cooper, 1960

Type Species.--Productella pyxidata Hall, 1858, p. 149 (by original designation).

Diagnosis.--Shell small, hemispherical, concavo-convex, non-geniculate, with greatest width near mid-length; interarea low; hinge-line usually short. Ornamentation consists of concentric growth lamellae and rugae that are commonly stronger on the pedicle valve. Concentric spine ridges and small spines in rough radial alignment on the pedicle valve; brachial valve with no spines but numerous endospines preserved as rounded nodes over the entire surface, more numerous anteriorly. Pedicle valve with small hinge teeth and no pseudodeltidium. Brachial valve with small sockets, bilobed cardinal process with alveolus rarely developed; prominent median septum, which bifurcates anteriorly (modified from Muir-Wood and Cooper, 1960, p. 149-150)

Discussion.--This assignment is based primarily on the exter-

nal characters of the genus, as internal structures are typically poorly preserved or absent. The genus most similar to Orbinaria is Productella, which has different internal structures, but Muir-Wood and Cooper (1962, p. 150) reported that Orbinaria can be distinguished externally from Productella by the more rounded outline, larger number of rugae, and more regularly arranged spines of Orbinaria. The subfamily Overtoniinae has several genera similar to Orbinaria (especially Overtonia and Avonia), but Orbinaria can be distinguished from these genera by its smaller size, lack of geniculation, rarer and less distinct costae, and more regularly arranged spines (Muir-Wood and Cooper, 1960, p. 183-201).

Orbinaria pyxidata (Hall,

Pl. , figs. 10,

Productus pyxidatus Hall, 1858, p. 498, pl. 13, fig. 8a-e.

Productella pyxidata (Hall). Hall, 1883, pl. 17) 48, fig. 34; Rowley, 1908, p. 77, pl. 17, figs. 5, 30-36; Weller, 1914, p. 100, pl. 19, figs. 1-21; Branson, 1938, pl. 20, fig. 9, Williams, 1943, p. 76, pl. 7, figs. 61-67 (further synonymy)

Orbinaria pyxidata (Hall). Muir-Wood and Cooper, 1960, p. 377, pl. 35, figs. 1-26; Muir-Wood, 1965, p. H465, fig. 298: 2A, B

Diagnosis.--A small, subelliptical species of Orbinaria with widely variable surface ornamentation. Pedicle valve moderately convex; ornamentation of rugae and concentric growth lamellae; some with scattered or radially aligned, long, thin spines developed on concentric spine ridges. Brachial valve rather deeply concave, becoming a little flattened at the cardinal margins; ornamentation typically somewhat deflected toward the cardinal margins; nodes in brachial valve sometimes

anged in strongly radiate pattern (modified from Rowley, 1908, p. 77; and Weller, 1914, p. 100-101).

Discussion.--Although there is wide variation in the surface ornamentation of this shell, the distinctive characters of the species make this somewhat uncommon form from units 1 and 3 of the Bakken member fairly easy to recognize. The specimens are disarticulated and are preserved mostly as complete molds of the exterior that are commonly somewhat crushed. The pedicle valves are poorly preserved or fragmental; they have strong concentric ornamentation and uncommonly have a few randomly scattered spine bases. The brachial valves have less pronounced concentric ornamentation and typically have nodes that are moderately to strongly radially aligned. The pedicle valves are generally smaller than those from the Louisiana Limestone that were illustrated by Williams (1943), although he reported (p. 77) a considerable variation in the size of his specimens. The largest pedicle valve in this study is about 8 mm wide and 7.5 mm long and the largest complete brachial valve is 10.3 mm wide and 8.7 mm long. Interareas are too low to be seen.

Comparison.--O. pyxidata is a characteristic form from the Louisiana Limestone and several Lower Mississippian rock units in the Mississippi Valley; fossils from early Mississippian rocks in western Canada have been compared to O. pyxidata by Brown (1952), Brindle (1960), and Nelson (1961). This species has not been reported from the Bakken's depositional complex in the western United States, however, although an undetermined species of Orbinaria that appears similar to O. pyxidata has been found in the Leatham Formation and the Leatham Member of the Pilot Shale. The siltstone member of the Exshaw Formation con-

tains O. concentrica, which was reported by Muir-Wood and Cooper 1962, p. 150) to be the only other species of Orbinaria O. concentrica is a widespread Kinderhookian species that has been reported (e.g., Williams 1943) to appear similar to O. pyxidata. O. pyxidata can usually be distinguished from O. concentrica by its greater width, fewer and less well-developed rugae in the umbonal area, less convex pedicle valve, smaller and less incurved pedicle beak, more concave brachial valve, and smaller auricles of O. pyxidata (Weller, 1914, p. 99-100; Williams, 1943, p. 77). These features are usually enough to distinguish the Bakken specimens from O. concentrica, but some of these features are variable in the Bakken specimens; Williams 1943, p. 77) reported that both of these species have considerable variation in size and surface markings that can cause individuals to be difficult to distinguish

Material and Occurrence.--Eighteen valves were found, with there being twice as many brachial valves as pedicle valves. Almost all of the specimens are from Unit 3 of the middle member; these were found in NDGS Well Nos. 2618, 2967, 3167, 4340, 5088, 7887, 8069, 8177, and 9351; two specimens are from near the bottom of unit 1 of the middle member in NDGS Well No. 5088.

Family Overtoniidae Muir-Wood and Cooper, 1960

Subfamily Overtoniinae Muir-Wood and Cooper, 1960

Genus Rhytiophora Muir-Wood and Cooper, 1960.

Type Species.--Productus blairi Miller, 1891, p. 79 (by original designation)

Diagnosis.--Shell medium-sized, subquadrate, slightly concavo-convex; both valves geniculate with short curved trails and some with a variably developed anterior rim; pedicle umbo rounded with beak extend-

ing slightly over hinge; venter flattened, flanks steep; greatest width commonly near anterior margin; auricles distinct and slightly convex. Pedicle valve ornamentation of narrow, irregular rugae across the visceral disc and numerous prostrate or erect spines set on rugae and spine ridges; spine ridges increase in length anteriorly where they commonly align in a radiating pattern. Brachial valve with rugae on visceral disc and with crowded growth lines and rare spines located mostly on the trail. Interior of pedicle valve unknown; brachial valve interior with small, bilobed cardinal process and broad-based septum extending to mid-length of visceral disc; septum becomes narrower and more prominent anteriorly. Endospines elongated into long ridges in concentric rows toward the anterior margin (modified from Muir-Wood and Cooper, 1960, p. 192).

Rhytiophora arcuatus (Hall, 1858)

Pl. 1, figs. 21-23, 33

Productus arcuatus Hall, 1858, p. 518, pl. 7, fig. 4a-b; Weller, 1901, p. 160, pl. 14, fig. 23, p. 185, pl. 16, fig. 15; Weller, 1914, p. 107, pl. 13, figs. 1-8, 29-32; Hyde, 1953, pl. 10, figs. 1-5.

Productella arcuata (Hall). Hall, 1883, pl. 17 48, figs. 31, 32; Hall and Clarke, 1892, pl. 17, figs. 31, 32

Rhytiophora arcuatus (Hall). Muir-Wood and Cooper, 1960, p. 192, pl. 51, figs. 1-16

Dictyoclostus arcuatus (Hall). Brown, 1952, p. 87; Nelson, 1961, pl. 5, figs. 14-16.

Rhytiophora? arcuatus (Hall). Rodriguez and Gutschick, 1967, p. 372, pl.

42, figs. 11-14, 16-19, 26.

(see Carter and Carter, 1967, p. 201 for further synonymy)

Diagnosis.--A small, strongly convex species of Rhytiophora having a short hinge, flattened ears, and steep lateral slopes. Costae poorly defined toward the posterior, bifurcating in the umbonal region and becoming stronger and somewhat coalesced anteriorly (modified from Rodriguez and Gutschick, 1967, p. 372)

Discussion.--This is a fairly common form from units 1 and 3 of the middle member that is recognized mostly by its external characteristics. Particularly distinctive features of this form are the rugose venters and the common occurrence of wavy growth lines especially crowded near the anterior of the trails. The specimens are mostly poorly preserved and disarticulated partial molds of the exterior that are commonly crushed and fragmented. On decorticated specimens the entire venter is covered with minute pustules that seem to coalesce, making a wavy textile-like pattern across the pronounced rugae; this is not present on the trail of the same specimens. The most complete pedicle valve found during this study (Pl. 1, figs. 21, 22) is about 22 mm wide; its length could not be measured because the specimen is crushed at the point of geniculation. An uncrushed, but incomplete and partly pyritized, pedicle valve is at least 23.2 mm long and about 6 mm high. The largest brachial valve is 19.8 mm wide (as determined from its half-width) and its length up to its point of geniculation is 15 mm. Spines are rarely found attached to the shells but are commonly found in the enclosing matrix where they are sometimes numerous and up to 15 mm long.

The specimens are similar to forms from the Banff Formation assigned to this species by Nelson 1961 and closely resemble those

described and illustrated from the Sappington by Rodriguez and Gutschick (1967), who questioned the generic assignment of their specimens because ~~of the lack of visible~~ internal structures and auricles. These features are generally missing in the Bakken specimens as well, although one brachial valve has flattened, well defined auricles about 3 mm long. In addition, the interior of one pedicle valve, with the umbonal region nearly filled in with matrix, displays a transverse section through the short, thin, slightly divergent dental lamellae which, as mentioned, are hitherto unknown in this genus. Rodriguez and Gutschick (1967, p. 374) compared their specimens from the Sappington with the holotype and found theirs to differ externally only in the spacing of the costae near the anterior margin. They reported that the holotype has 10 to 11 costae within one centimetre, whereas those of the Sappington have five to eight costae per centimetre. Those from the Bakken have about eight costae in the same distance.

Material and Occurrence.---This is a common species in unit 3 of the middle member, where it is locally abundant, but poorly preserved, in beds of shale and siltstone up to a few inches thick. Specimens from unit 3 were collected or noted in NDGS Well Nos. 2618, 4340, 4958, 5088, 7851, 7887, 8069, and 8177. Six pedicle valves and one brachial valve were found scattered in unit 1 in NDGS Well Nos. 4958, 5088, and 8069.

In addition, several immature and silicified productoid brachial valves were found in the residues of an acidized core piece from near the base of the middle member in NDGS Well No. 2967, and a similar small specimen was found on a bedding plane near the top of the upper shale member in NDGS Well No. 413. These specimens are fragments of planar



beak areas and are less than about 2.0 mm wide and long.

Order RHYNCHONELLIDA

Superfamily RHYNCHONELLACEA Gray

Family Camarotoechiidae Schuchert and LeVene, 1929

Subfamily Camarotoechiinae Schuchert and LeVene, 1929

Genus Rugaltarostrum Sartenaer,

Type Species.--Leiorhynchus madisonense Haynes, 1916, p. 39, by original designation).

Diagnosis.--Shell small to large; transverse to subovate; greatest height of shell commonly at anterior margin of linguliform extension (tongue). Sulcus and fold start at or near beak area, widen rapidly, and contain a few rounded, bifurcating plicae that start at the beak. Flanks smooth or finely capillate. Dental plates slender and slightly divergent in beak area, becoming parallel and then convergent anteriorly. Brachial valve with short, slender median septum supporting a wide, cup-shaped, and uncovered septalium; hinge plates plane (modified from McLaren, 1965, p. H583; and Sartenaer, 1969, p. 29-30).

Discussion.--Rugaltarostrum appears similar to Leiorhynchus, but Sartenaer (1961b) redefined Leiorhynchus and excluded this middle to late Devonian genus from rocks of Famennian age. He reported (1961a, p. 5) that Rugaltarostrum is easy to distinguish from Leiorhynchus by the less convex brachial valve and better developed sulcus and fold that start closer to the beak of Rugaltarostrum. Sartenaer (1969, p. 30) reported that Rugaltarostrum differs externally from Calvinaria by the possession of a less convex pedicle valve, a sulcus and fold present in the beak area, and the more variably developed plicae in the fold and sulcus.

Rugaltarostrum madisonense (Haynes, 1916)

Pl. 1, figs. 25, 32

Leiorhynchus madisonense Haynes, 1916, p. 39, pl. 8, figs. 11-13; Baldwin, 1943, p. 146; Crickmay, 1952, p. 588.

Rugaltarostrum madisonense (Haynes). Sartenaer, 1961a, p. 6, pl. figs. 5a-e, pl. 2, fig. D; McLaren, 1965, p. H583, fig. 456: 3a-g; Sartenaer, 1969, p. 31, pl. 3, figs. 1-13, text-figs. 4-6 (further synonymy)

Diagnosis.--"The species is distinguished by small size, sulcus and fold starting at some distance from the beaks, number and distribution of costae, rare division of median costae, and middle median costa(e) not starting at the beak of the fold" (Sartenaer, 1969, p. 37).

Discussion.--Disarticulated valves that match the characteristics of this species were rarely found on bedding planes from near the base of the lower black shale. The valves are preserved largely as decalcified molds of the exterior that are very thin, which often results in their being crushed and fragmented. Internal features are generally not preserved, although a short, thin median septum was seen on the brachial valves. Pedicle valves have two plicae in the sulcus and brachial valves have three plicae on the fold; the tongues were broken away. No plicae were seen on the flanks, although two specimens show fine concentric growth lines over the surface of the shell and extremely faint, fine capillae near the anterolateral margins. The most complete pedicle valve is 17.4 mm wide and the length seen i.e., not including the broken off tongue) is 13.4 mm. This specimen has an apparent height of about 1 mm, although the shell is somewhat crushed and thus slightly distorted. The brachial valves are not complete

enough for measurement but appear slightly wider than long; the estimated width of one, as determined from nearly a half-width, is 13.6 mm; the other has an apparent length of 12.6 mm. These valves are crushed and incomplete to determine their height.

Comparison.--Sartenaer (1967, p. 1052) stated that three species of Rugaltarostrum occur in North America, and all three are from the upper part of the Trident Member and the lower part of the Sappington Member of the Three Forks Formation in Montana. He indicated that R. madisonense is the most widespread of the three species, as it has also been reported from the Three Forks Formation in Idaho and other Upper Devonian rocks in western Canada. Sartenaer (1969, p. 37) reported that R. madisonense is distinguished from the other two species of Rugaltarostrum (R. gibbosum and R. jeffersonense) by its smaller size, absence of the sulcus, fold, and costae in the beak area, the one to three plicae in the sulcus, two to four plicae on the fold, and the rare division of the costae

Material and Occurrence.--The specimens consist of two pedicle valves, two brachial valves, and three indeterminate fragments; all are from within the bottom few feet of the lower black shale in NDGS Well Nos. 1679 and 2383.

Family Wellerellidae Likharev in Rzhonsnitskaya

Subfamily Wellerellinae Likharev in Rzhonsnitskaya

Genus Allorhynchus Weller, 1910

Type Species.--Rhynchonella heteropsis Winchell, 1865, p. 121  
(by original designation)

Diagnosis.--Shell rhynchonelliform, relatively small; well developed sulcus and fold in anterior one-half of shell; well developed

subangular to rounded costae; costae typically well defined in beak area. Pedicle valve interior with slender dental lamellae. Brachial valve interior with divided hinge-plate, no median septum, and no crural cavity (modified from Weller, 1914, p. 197; and Schmidt, 1965, p. H592)

Discussion.--No definite assignment of the rhynchonellids from the middle member can be made because of a general lack of interiors; Weller 1914, p. 197) and LaRoque and Marple (1955, p. 99) have reported that Allorhynchus is externally indistinguishable from Camarotoechia and Rhynchopora.

?Allorhynchus heteropsis (Winchell, 1865)

Pl. 2, fig. 12

Rhynchonella heteropsis Winchell, 1865, p. 121.

Camarotoechia? heteropsis (Winchell). Weller, 1901, p. 156-157, pl. 13, figs. 9-13.

Allorhynchus heteropsis (Winchell). Weller, 1910, v. 21, p. 509, fig. 8; Weller, 1914, p. 197-199, pl. 24, figs. 73-81, text-fig. 11; Shimer and Shrock, 1944, p. 311, pl. 118, figs. 66-68; Schmidt, 1965, p. H592, fig. 1a-i.

Diagnosis.--Shell small, dorsibiconvex, transversely elliptical; beaks sharp and strongly incurved. Sulcus and fold begin near or slightly anterior to the midlength and contain three or, rarely, four costae. Four to six costae mark each lateral slope; lateral costae are best developed and most angular nearest the margins of the sulcus and

Pedicle valve interior with weak hinge teeth supported by short, thin dental lamellae. Brachial valve interior with divided hinge-plate lacks supporting septa (adopted from Weller, 1914, p. 197-198).

Discussion.--This is a common form from unit 3 of the middle member that is similar in size, shape, and ornament to this Lower Mississippian species. No occurrence of the species has been noted in the Bakken's correlatives in the western United States or in the Louisiana Limestone. The Bakken specimens appear similar to a form from the Sappington and the Louisiana Limestone that has been somewhat loosely ass-

to Camarotoechia tuta by Rodriguez and Gutschick 1967) and Williams 1943), respectively; both noted that their identifications were tenuous because of a lack of internal structures. Also, as Rodriguez and Gutschick 1967) pointed out, Sartenaer 1961c) had redefined Camarotoechia and restricted its range to the Middle Devonian. The Bakken specimens differ most conspicuously from "C." tuta from the Sappington and Louisiana by being of about twice the size of those specimens; they also differ by having a generally better defined sulcus and fold and the greatest width of the Bakken specimens is located more posteriorly than those from the Sappington and Louisiana. The Bakken specimens differ from rhynchonellids from the Exshaw siltstone member assigned to C. allani and C. metallica by Warren 1937) by being smaller and having fewer costae

A long median septum was seen in molds of the interiors of two ped- valves but other internal structures were not visible. The Bakken specimens are decorticated and disarticulated and do not lend themselves well to serial sectioning, a method by which the interiors of rhynchonellids are commonly studied. Few complete valves were found; most are either fragmental or partly buried in the matrix; no interareas were seen. The number of costae in the sulcus and fold of the Bakken specimens is either three or, about as commonly, four; the specimens have

four to six costae on each lateral slope. Pedicle valves are from about 13 to 14 mm wide and 11 mm long, with a height of about 2 mm. Brachial valves are about 12 to 14 mm wide and 10 to 11 mm long, and about 3 mm high.

Material and Occurrence.--A total of 15 valves that appear similar to A. heteropsis were found in unit 3 of the middle member. These specimens consist of six pedicle valves, six brachial valves, and three fragments, and were found in NDGS Well Nos. 607, 2618, 2967, 4340, and 8177. This form was found to be locally abundant in unit 3, as ten shells were found on a partial piece of a three and one-half inch core about one inch thick (Pl. 2, fig. 11)

?Allorhynchus acutiplicatum Weller, 1914

Pl. 2, fig. 11

Allorhynchus acutiplicatum Weller, 1914, p. 201-202, pl. 24, figs 83-86.

Diagnosis.--Shell small, dorsibiconvex, subovate, wider than long, greatest width anterior of midlength. Brachial valve similar to A. heteropsis but more convex and with five costae on the fold and seven to ten on each lateral slope (adopted from Weller, 1914, p. 201-202).

Discussion.--A single, well-preserved exterior of a rhynchonellid brachial valve from unit 3 of the middle member superficially resembles this Upper Mississippian species from Missouri, although a lack of visible internal structures in the specimen prevents a more definite assignment. The specimen differs from the other rhynchonellids of unit 3 by its greater convexity and by having more costae, with 5 costae on the fold and 8 on each lateral slope. The specimen is 11.8 mm wide, 10.3 mm long, and about 6 mm high

Material and Occurrence.--The specimen is from unit 3 of the middle member in NDGS Well No. 607.

Order SPIRIFERIDA

Suborder ATHYRIDIDINA

Superfamily ATHYRIDACEA McCoy, 1844

Family Athyrididae McCoy, 1844

Subfamily Athyridinae McCoy, 1844

Genus Composita Brown, 1849

Type Species.--Spirifer ambiguus Sowerby, 1823, p. 105, (by original designation).

Diagnosis.--Small to moderately large, biconvex, and subovate, subquadrate, or subpentagonal. Surface smooth or pauciplicate, often with fine, nonlamellar growth lines. Sulcus and fold strong to nearly obsolete. Circular foramen at the extremity of a prominent beak; pedicle valve closely incurved over the brachial beak. Brachial valve with strong to nearly obsolete fold that may have a medial furrow. Dental plates short, cardinal plate perforate apically, and may develop posteriorly extended flanges; brachial myophragm may be present; jugum essentially as in Athyris (modified from Boucot, et al., 1965, p. H662; and Grinnel and Andrews, 1964, p. 228)

Composita sp. 1

Pl. 1, fig. 12

Discussion.--Two specimens from the middle member are assigned to an undetermined species of this genus on the basis of their smooth surface with fine growth lines, subpentagonal outline, and the greatest width being located near the mid-length. Neither specimen shows inter-

nal structures. One specimen is a poorly preserved brachial valve (possibly articulated) and the other is a nearly complete articulated specimen chipped free of the matrix. The umbo and beak area of the pedicle valve were truncated by slabbing of the core done in previous studies. A sulcus and fold are obsolete in the posterior portion of the articulated specimen but appear sharp and well defined in the anterior part of the shell; this sharpness, however, appears to be due in part to lateral crushing of the valves in the anterior area. The surface of the articulated shell is decorticated and has been partly replaced by pyrite and silica. This preservation has partly obscured the ornamentation; several growth lines are visible near the anterior end of the pedicle valve, and four growth lines are visible over the posterior two-thirds of the brachial valve. The reconstructed width of this shell, as determined from the least distorted half of the shell, is 14 mm, its length from the beak of the brachial valve to near the anterior margin is mm, and the height of the specimen is about 1 mm. The other specimen is too poorly preserved for measurement but appears to be of about the same size as the articulated specimen.

Comparison.--The Bakken specimens appear very similar to illustrations of a specimen from the Sappington Member that was assigned to Composita cf. C. athabaskensis by Rodriguez and Gutschick 1967, pl. 44, figs. 21-24). They reported (p. 380), however, that their specimens have much variation in the shell outline, length-width ratio, strength of fold and sulcus, and convexity of the valves. Grinnel and Andrews (1964, p. 228) reported that this sort of variation in the shape of valves is typical in other coeval species of Composita as well, and Brown (1952, p. 65) reported that the external variability of C. atha-



baskensis, C. madisonensis pusilla, and C. humilus from the Banff

Formation can cause individuals of these three taxa to appear indistinguishable; thus it would seem that the Bakken specimens could belong to any one of these taxa

Material and Occurrence.--The two specimens come from NDGS

No. 4340, where they were found within a few inches of each other in unit 3 of the middle member

Composita sp. 2

Pl. 1, fig. 13

Discussion.--A single pedicle valve from unit 3 of the middle member appears similar to Composita sp. 1 but differs from that species by being subovate, wider than long, and by having a less distinctive sulcus in the anterior half of the shell. This valve appears similar to an uncommon form from the Sappington that Rodriguez and Gutschick 1967, p. 379) identified as Camarophorella cf. C. buckleyi. They pointed out

based solely on external features, species of Composita can be easily confused with some forms of Camarophorella. They distinguished their specimens from species of Composita by the smaller size and the presence of a sulcus in the brachial valves of their specimens. Such a distinction could not be made here because no internal structures or brachial valves were found in the Bakken, and species of Composita can be of about the same small size as the Bakken specimen. The rounded outline of the Bakken specimen is suggestive of Composita humilis from the Exshaw siltstone and overlying Banff Formation in western Canada. The specimen is a partly decorticated mold of the exterior that is nearly complete, although the beak is not exposed and the growth lines ascribed to the genus are nearly obscured because of the decortication.

The shell is 15.5 mm wide, 13.8 mm long, and about 5 mm high.

Material and Occurrence.--The Bakken specimen is from near the top of Unit 3 in NDGS Well No. 2618.

Suborder SPIRIFERIDINA

Superfamily SPIRIFERACEA King, 1846

Family Mucrospiriferidae Pitrat, 1965

Genus Tylothyris North, 1920

Type Species.--Cyrtia laminosa McCoy, 1844, p. 137, (by original designation).

Diagnosis.--"Shell small or of medium size, spiriferoid in external form, the mesial fold and sinus non-plicate or with a single median plication, the lateral slopes of the valves with simple, rather strong plications, both valves marked by concentric, lamellose lines of growth of greater or less strength. Pedicle valve with an arched cardinal area of moderate height, and an open delthyrium; internally the dental lamellae are well developed and between them is a well defined median septum. The brachial valve is similar to Spirifer internally, with a brachidium as in that genus" (Weller, 1914, p. 300)

Tylothyris clarksvillensis (Winchell, 1865)

Pl. 2, figs. 9, 10

Spiriferina clarksvillensis Winchell, 1865, p. 119; Rowley, 1908, p. 83, pl. 18, figs. 10-12

Delthyris clarksvillensis (Winchell). Weller, 1914, p. 301-302, pl. 36, figs. 6, 7; Williams, 1943, p. 83-84, pl. 8, figs. 29-31.

Tylothyris clarksvillensis (Winchell). Rodriguez and Gutschick, 1967, p.

pl. 43, figs. 22-27, text-fig. 5.

Diagnosis.--"A small species of Tylothyris of Louisiana age bearing from four to seven plications on each lateral slope; median septum in the pedicle valve extending to one-half the shell length or some- less" (Rodriguez and Gutschick, 1967, p. 376).

Discussion.--This is an uncommon shell from the middle member that is generally poorly preserved but is easily recognized because of its distinctive exterior, which Williams (1943) reported to be easily distinguishable from the other brachiopods with which it is associated. The Bakken specimens are assigned to this species largely on the basis of their small size, wide, rounded, non-plicated fold and sulcus, with the fold only slightly raised, and four to six wide, rounded plicae on lateral slope. The Bakken material consists of fragmental to nearly complete disarticulated valves that are heavily decorticated commonly crushed, and preserved mostly as partial molds of the exterior. The strong growth lamellae are visible on several of the specimens and the high interarea of the species was seen on one specimen, although it is incomplete and poorly preserved. A trace of part of a median septum could be seen in one pedicle valve, but internal molds of the pedicle valve were never complete enough so the septum could be followed for its full extent. The most complete pedicle valve has an estimated width of 19.2 mm and a length of 1.8 mm; a near-complete brachial valve is about 12.0 mm wide and 8. mm long.

Comparison.--Weller (1914, p. 302) reported that T. missouriensis Weller is a Kinderhookian species that most resembles T. clarksvillensis; T. clarksvillensis can be distinguished from T. missouriensis by its wider shell, less convex pedicle valve, and greater number of

lateral plicae. Although these distinctions seem adequate to distinguish the Bakken specimens, Branson 1938, p. 137) reported that the shell size and number of lateral plicae are more variable than Weller indicated and that individuals of T. missouriensis can be indistinguishable from T. clarksvillensis. Rodriguez and Gutschick (1967, p. 376) reported that another species similar to T. clarksvillensis is T. minima, which differs from T. clarksvillensis by having finer growth lamellae (averaging about five to six per millimetre) whereas specimens from the Bakken, as well as those from the Sappington and the Louisiana Limestone, have two or three per millimetre.

Material and Occurrence.--Eleven specimens (seven pedicle valves and four brachial valves) were found in unit 1 of the middle member in NDGS Well Nos. 607, 2967, 4340, 4958, 5088, and 8069.

Family Syringothyrididae Frederiks,

Subfamily Syringothridinae Frederiks,

Genus Syringothyris Winchell, 1863

Type Species.--Spirifer carteri Hall, 1857, p. 170, (by subsequent designation of ICZN Opinion 100, 1928, p. 377).

Diagnosis.--Shells ranging from small to very large, spiriferoid in outline, with high interarea that can be flat, concave, or convex. Cardinal area divided into three areas, a central area (perideltidium) that includes the delthyrium and is marked by both horizontal and vertical lines, and two marginal areas marked by horizontal lines only; the areas are separated by two lines which start at the apex and run obliquely toward the hingeline. Lateral slopes with numerous nonbifurcating plicae; fold and sulcus bald; micro-ornament of minute granules imparting a textile-like surface to the shell. Interior of

pedicle valve with long dental plates, delthyrial plate and syrx; median septum absent (modified from Pitrat 1965, p. H692; and Weller 1914, p. 384).

Discussion.--Syringothyris is distinguished from Pseudosyrinx by a syrx in the delthyrium; this internal structure is poorly preserved or absent in the Bakken specimens. Williams (1943, p. 87) reported that the absence of a syrx in Syringothyris could be due to lack of preservation, and Hyde (1953, p. 264) reported that its absence could also be due to a variability in its development in some species of this genus, as he found a form of Syringothyris in Ohio that was gradational with Pseudosyrinx. He compared his gradational form of Syringothyris to S. hannibalensis this is the species that the Bakken specimens appear the most similar to, and is a species that is characteristic of the Louisiana Limestone and rocks of the Bakken's depositional complex (Gutschick and Rodriguez, 1979, p 51).

Two other genera similar to Syringothyris are Asyrinxia and Pseudosyringothyris. Asyrinxia lacks a syrx and differs from Syringothyris by the presence of several weak plications in the sulcus in the former. Pseudosyringothyris differs from Syringothyris by having an incompletely developed syrx; Pitrat (1965, p. H692) has reported that Pseudosyringothyris is known only from the lower Permian of Russia. Both the internal and external features of the brachial valves of Syringothyris are generally similar to those of Spirifer (Weller, 1914, p. 385) but the Bakken specimens are distinguished from Spirifer by being larger, having a bald fold that becomes more prominent anteriorly, and by having coarse, rounded plicae. (Weller, 1914, p. 389)

Syringothyris hannibalensis (Swallow, 1860)

Pl. 2, figs. 7, 8, 13, 15

Spirifer (Cyrtia?) hannibalensis Swallow, 1860, p. 647Syringothyris carteri (Swallow), Schuchert, 1890, p. 30 (in part).

Syringothyris hannibalensis (Swallow), Hall and Clarke, 1895, p. 647;  
 Rowley, 1908, p. 82, pl. 18, figs. 6-9, pl. 19, figs. 4, 5; Weller  
 1914, p. 388, pl. 68, figs. 1-7; Williams, 1943, p. 86, pl. 8, figs.  
 51-56 (further synonymy); Brown, 1952, p. 102; Rodriguez and Gutschick,  
 1967, p. 376-377, pl. 43, figs. 1-6.

Syringothyris cf. S. hannibalensis (Swallow), Brindle, 1960, p. 100, pl.  
 26, fig. 2

Diagnosis.--"A medium to large punctate species of Syringothy-  
 about twice as wide as long, having medianly ridged syringal plate  
 bearing a short, wide, blunt syrinx" (Rodriguez and Gutschick, 1967, p.  
 376).

Discussion.--This is an uncommon form from the middle member  
 that is recognized primarily by the large size, general spiriferoid  
 shape, rounded extremities, high interarea, non-plicated fold and sul-  
 and numerous simple lateral plicae. The shells are large (gener-  
 ally larger than those from the Sappington) and have a somewhat variable  
 shape, similar to the variability of specimens from the Louisiana Lime-  
 stone illustrated by Williams 1943). Most of the Bakken specimens are  
 decorticated exteriors and the textile-like micro-ornamentation was not  
 seen on specimens of this species. No more than 16 plicae were found on  
 the lateral slopes of any valve, but there may be more, as the decorti-  
 cation appears to have obscured the plicae near the cardinal extremi-

ties. Three pedicle valve interareas, two of which are articulated were found

The articulated valves have the pedicle beak area broken away and display strong dental plates that run from the beak area to the hinge-line; one of these specimens displays a cross-section of the syrx. The disarticulated interarea with the unbroken beak shows a complete exterior of the delthyrium but no syrx was found where the matrix below the delthyrium was chipped away. The vertical lines of the perideltidium can be seen in some places in two of the interareas, but the external shell material in the interareas was not found to extend 14 mm beyond the delthyrium, as the rest is either broken away or cut off by the core barrel. The interareas seem to be strongly apsacline, but this may be due in part to compaction. The anterior halves of the articulated shells are crushed, which is due in part to the thinness of the shell as reported by Rowley 1908, p. 83). The one complete delthyrium has a delthyrial angle of about 25 degrees and a pseudodeltidial plate occupying its apical one-third; the delthyrium is about 19 mm high and 11.6 mm wide at its base. The widest pedicle interarea seen is about 66 mm wide (reconstructed from half-width), and the most complete brachial valve is 41.2 mm wide and 26 mm long.

Comparison.--Rodriguez and Gutschick (1967, p. 377) reported that S. hannibalensis is similar to S. typus, but differs from that species by having a smaller size, a proportionally lower interarea, and a shorter, less well-developed syrx (Weller, 1914, p. 397). Williams (1943, p. 87) reported S. newarkensis occurs rarely in the Louisiana Limestone, and has a relatively higher and narrower delthyrium than does S. hannibalensis (Weller, 1914, p. 395).

Material and Occurrence.--Twelve shells, mostly brachial valves, were found in unit 1 of the middle member in NDGS Well Nos. 607, 999, 2618, 3167, 4340, 5088, and 8069.

Syringothyris halli Winchell, 1863

Pl. 2, figs. 5, 6

Syringothyris halli Winchell, 1863, p. 8; Weller, 1901, p. 158, pl. 13 figs. 1-3; Weller, 1914, p. 390, pl. 52, figs. 13-23.

Diagnosis.--Similar to S. hannibalensis, but much smaller and proportionally shorter (modified from Weller, 1914, p. 391).

Discussion.--This is an uncommon form from unit 3 of the middle member that resembles specimens of S. hannibalensis from unit , but differs from those specimens by having a much smaller size and shorter length; the largest specimen from unit 3 is nearly one-half the size of the largest syringothyrid from unit 1. Two pedicle valves were found, both of which display the high interarea and long dental plates characteristic of the genus, and one displays a portion of the syrx (Pl. 2, fig. 6). The shells of this species are thin and crushed, fragmental, and heavily decorticated. External ornament is generally poorly preserved, although the textile-like (quincuncial) microramentation of this genus can be seen on one fragment of a brachial valve. The valves from the Bakken are slightly larger than those reported by Weller (1914) from the Kinderhookian of the Mississippi Valley; one pedicle valve is about 32 mm wide, about 13 mm long, and, although partly crushed and the apex is missing, about 10 mm high. The hingeline of the specimen with the syrx exposed, the largest specimen, is about 40 mm long and the interarea is about 13 mm high. None of the brachial valves is complete enough for measurement; these brachial valves are distinguished from



brachial valves of species assigned to Spirifer, with which they are closely associated, largely by the broad, elevated, and noncostate fold of S. halli (Pl. 2, fig. 6).

Material and Occurrence.--One pedicle valve and three brachial valves were found in unit 3 of the middle member in NDGS Well No. 4958, and one pedicle valve was found in unit 3 in NDGS Well No. 8069.

Family Spiriferidae King, 1846

Genus Spirifer Sowerby, 1816

Type Species.--Conchylolithus (Anomia) striatus Martin, 1793, pl. 23 (by subsequent designation of ICZN Opinion 100, 1928, p. 377)

Diagnosis.-- "Biconvex; almost equidimensional to moderately transverse; cardinal extremities generally rounded, providing hinge line somewhat less than maximum width; lateral plications numerous, generally bifurcating adjacent to fold and sulcus, elsewhere generally simple, rarely somewhat fasciculate; fold and sulcus with numerous bifurcating plications; micro-ornament typically consisting of obscure concentric growth lamellae and capillae; pedicle valve interior with short, stout dental plates, lacking median septum and delthyrial plate; brachial valve interior without crural plates" (Pitrat, 1965, p. H704)

Spirifer greenockensis Brown, 1952

Pl. 2, figs. 1-3

Spirifer greenockensis Brown, 1952, p. 64, 98-99, pl. 4, figs. 5a-c, text-fig. 14; Nelson, 1961, pl. 5, figs. 11-13, pl. 7, figs. 8-9.

Spirifer cf. S. greenockensis Brown. Rodriguez and Gutschick, 1967, p. 377-378, pl. 43, figs. 9, 10, 17-21, text-fig. 6A.

Diagnosis.--"A Kinderhookian species of Spirifer having seven

to ten plications in the sulcus and 20 to 30 lateral plications; ears mucronate in young stages, shell margin semicircular in adult forms" (Rodriguez and Gutschick, 1967, p. 377)

Discussion.--A few shells from near the top of the middle member closely resemble Brown's descriptions and illustrations of the type material from the Banff Formation in Alberta. The Bakken specimens also appear similar to specimens from the Sappington Member of the Three Forks, although the rarely preserved interareas and the crushed and deformed condition of the Sappington material prevented Rodriguez and Gutschick from making a definite assignment to this species. The shape of the interarea varies somewhat between those from Alberta, Montana and North Dakota; Brown's type material from the Banff Formation in Alberta has a low triangular interarea, those from the Sappington have subparallel interareas, and the Bakken specimens have nearly rectangular interareas. Rodriguez and Gutschick (1967, p. 378) reported that many of their specimens also differ from Brown's material by having bifurcations in the first three lateral plicae but this was not found to be the case in the Bakken material which, like Brown's specimens, has simple lateral costae. The Bakken specimens are decorticated, commonly crushed, and are mostly fragmental. Their identification is based largely on one complete and uncrushed pedicle valve (Pl. 2, fig. 1) and a nearly complete but slightly crushed articulated specimen that has the brachial valve and the interarea of the pedicle valve free of the matrix (Pl. 2, figs. 2, 3).

The complete pedicle valve is semicircular and rather strongly convex with the greatest convexity occurring in the umbonal area. This valve has about 20 simple costae on each lateral slope and an estimated

nine costae in the sulcus. Some of the costae in the sulcus bifurcate near the anterior margin in a manner that was diagrammed by Rodriguez and Gutschick (text-fig. 6). The shell material is broken away in the umbonal area, thus revealing most of the ovate muscle field, which is about 6 mm wide and 10      long and tapers anteriorly before terminating

the midlength of the valve. The specimen with the conjoined valves shows a strongly apsaclinic interarea that is about 4 mm high and has nearly parallel interarea margins. The delthyrium is open and 4 mm wide and about 3 mm high; the beak of each valve sharply overhangs the interarea. The brachial valve of this articulated specimen is much less convex than are the pedicle valves of this study and has a poorly defined

that contains about seven decorticated costae. The one uncrushed pedicle valve is about 7 mm high, 38 mm wide (as reconstructed from its half-width), and 30 mm long; the nearly complete brachial valve is flattened but is 36 mm wide (reconstructed from half-width) and 25.3 mm long.

Remarks.--Prior to Rodriguez and Gutschick's publication in the most commonly reported species of Spirifer from the Bakken correlatives was S. marionensis, which has been reported from the Louisiana Limestone by Williams (1943), and from the Leatham Formation and the Sappington Member of the Three Forks by Holland (1952). The presence of this species in the Mississippian S. marionensis zone of Canada was questioned by Green (1962, p. 296, footnote), however; and Rodriguez and Gutschick (1967, p. 378) stated that specimens of S. marionensis previously reported from the Sappington (e. g., Achauer, 1959) are probably immature individuals of the two species of Spirifer (which they said might be conspecific) that they found in the Sappington. Rodriguez

and Gutschick's description of the smaller forms from the Sappington is similar to Williams's description (p. 86) of the smaller forms of S. marionensis from the Louisiana Limestone, as both differ from their adult forms largely by their proportionally longer hingeline and sharper cardinal extremities. Juvenile features apparently tend to persist more in the adult forms of S. marionensis than in S. greenockensis; adult forms of S. marionensis differ from those of S. greenockensis by having "more diverging sides, sharper cardinal extremities, and a linear area with a resultant smaller and sharper beak and a more gentle posterior slope. It also has typically less ribs in the sinus, and the lateral ribs near the sinus bifurcate more commonly." (Brown, 1952, p. 99)

As in the forms of Spirifer from the Louisiana and the Sappington, most of the smaller Bakken specimens of Spirifer are more transverse and mucronate with fewer lateral and sulcal plicae than the larger shells; but these traits are seen in some of the larger Bakken specimens as well, and two of the smaller pedicle valves (about 20 mm wide and 15 mm long, reconstructed) have an ovate shape and high convexity that appear similar to the adult forms of S. greenockensis. For these reasons, the Bakken spirifers are separated into two species, although the incomplete and deformed nature of the Bakken material, as well as the variation in the shape of the shell of S. greenockensis (as reported by Rodriguez and Gutschick), makes this separation somewhat tentative.

Comparison.--Brown (1952, p. 99) differentiated S. greenockensis from similar species by saying, "S. centronatus Winchell has sharper ribs, with greater interspaces, and most commonly 3 to 5 ribs in the sinus. S. striatus madisonensis Girty has a higher cardinal area and the lateral ribs are said to bifurcate near the anterior margins. S.

albapinensis Hall and Whitfield is a proportionally wider form, with relatively prominent boundary plicae." Both S. centronatus and S. albapinensis have been reported from the Exshaw siltstone member by Warren (1937). The specimens from the Bakken differ from a third species of Spirifer that Warren (1937) reported from the Exshaw siltstone, S. albertensis, by being of nearly twice the size than that species and by having a less well-defined sulcus.

Material and Occurrence.--The shells are in close association with Spirifer sp. in unit 3 of the middle member. Among the numerous fragments of Spirifer in this unit, four pedicle valves and three brachial valves from NDGS Well Nos. 4958, 5088, 7851, and 9351 were identified as S. greenockensis.

#### Spirifer sp

Pl. 2, fig. 16

Discussion.--This shell is similar to the smaller forms of Spirifer from the Louisiana Limestone and the Sappington and is characterized by its widely transverse spiriferid shape with sharp cardinal extremities, a moderate convexity with the greatest convexity in the umbonal region, sharply incurved beaks, a well-defined sulcus in the umbonal area that becomes obscure anteriorly, a poorly defined fold, and no more than seven simple costae in the sulcus. The largest of these are nearly as wide as adult forms of S. greenockensis, but only about one-half as long. The specimens are all incomplete and somewhat decorated, and many are partly crushed. The lateral slopes have about 25 simple costae each, three to five costae are visible in the sulcus, and five to seven costae were seen on the fold. The median costa extends back to the beak area and the other costae in the sulcus and fold are

seen to form through the bifurcation of the laterally bounding costae, with the inner costa going into the sulcus or fold. One fragment of a nearly straight interarea was found that is about 2 mm high and has an open delthyrium about 3 mm wide and 2 mm high. The largest specimen is a brachial valve about 30 mm wide (reconstructed from most of its half-width) and 15 mm long. The largest and most complete pedicle valve has a reconstructed width of about 34 mm and a length of about 14 mm.

Comparison.--The Bakken specimens differ from the indeterminate species of Spirifer from the Sappington (Rodriguez and Gutschick, 1967, p. 379) by being smaller and by having fewer lateral costae. Rodriguez and Gutschick (1967, p. 379) said that their form of Spirifer sp. is similar to S. cascadiensis from the Banff Formation in Alberta. A species of Spirifer from the Exshaw siltstone, S. centronatus, has a mucronate shape and three to five costae in the sinus and thus closely resembles many of the specimens of this study; the Bakken material is also of about the same size as S. centronatus. Brindle (1961, p. 16) compared a species of Spirifer from the middle member of the Bakken in Saskatchewan to S. osagensis, and Weller (1914, p. 314) reported that S. osagensis is a mucronate, small- to medium-sized species that has sometimes been confused with S. marionensis. Williams (1943, p. 85) reported that S. marionensis is distinguished from all other Mississippian forms of Spirifer by having interarea margins that remain parallel to near the cardinal extremities and thus form a parallelogram. This feature could not be seen in the Bakken material, however, as no sample of the interarea near the cardinal extremities was found; thus the material at hand is too fragmental to determine which, if any, of the above-mentioned species the Bakken specimens may belong to or if they

may instead represent immature or atypical forms of S. greenockensis.

Material and Occurrence.--About 50 shells, almost all of which are fragmental, were found in unit 3 in NDGS Well Nos. 105, 3167, 4340 4508, 4958, 5088, 7887, 8069, 8177, 8474, and 9351. One valve is a pedicle valve interarea from near the base of unit 2 in NDGS Well No. 527; this specimen is from the same piece of core that contains Syringopora sp..

Superfamily RETICULARIACEA Waagen

Family Elythidae Frederiks, 1919 (1924)

Genus Torynifer Hall and Clarke

Type Species.--T. criticus Hall and Clarke, 1894, pl. 84

Spirifer pseudolineatus Hall, 1858, p. 645; by original designation

Diagnosis.--Biconvex, moderately transverse with obtuse cardinal extremities; sulcus and fold weak or absent, ornamentation of concentric growth lamellae each of which bears a row of fine, double-barreled spines. Pedicle valve interior with distinct dental plates and median septum; brachial valve interior with low median septum (modified from Pitrat, 1965, p. H724; and Shimer and Shrock, 1944, p. 327)

Torynifer sp.

Pl. 1, fig. 35

Discussion.--This is a fairly rare form from near the top of the middle member (unit 3) that is recognized by its moderately to strongly transverse outline, rounded shell margins, greatest width being just posterior to the mid-length, weak radial ornamentation, and relatively prominent concentric growth lamellae. The shells are disarticu-

lated, largely fragmental, and badly decorticated; the surface ornamentation is poorly preserved or absent and a faint sulcus and fold are present on two of the specimens. The double-barreled spines, characteristic of elythids, were not preserved, but it is possible that the fine radiating ornament may be the result of alignment of the traces of these spines in the decorticated shells. The largest brachial valve (Pl. 1, fig. 35) is preserved as a mold of the interior in the beak area and the position of a median septum can be seen there. The shells range from small- to medium-sized, with the largest and most complete one being a brachial valve 23.3 mm wide, 15.7 mm long, and about 4 mm high; another nearly complete brachial valve (Pl. 1, fig. 35) is 16.7 mm wide and .4 mm long. One pedicle valve has a reconstructed width of about 19.4 mm, and its length from near the beak area to the anterior margin is 15.8 mm. This specimen and the smaller brachial valve are too crushed for a measurement of the shell height. Two additional fragments assigned to this species are too incomplete for their accurate measurement.

Comparison.--The presence of a median septum in Torynifer distinguishes this genus from Phricodothyris, which lacks one. The poorly preserved surface ornament and the lack of spines in the Bakken specimens makes them hard to distinguish from species of Reticularia, which normally has much more conspicuous concentric growth lamellae than do either Torynifer or Phricodothyris. Reticularia also differs from these genera by having uniramous spines set on the heavier lamellae. Pitrat (1965, p. H717) reported that Reticularia is not known to occur in North America, however, and forms in the family Reticularidae have a less transverse shape than do the Bakken specimens. The Bakken specimens are



more transverse than specimens assigned to Reticularia? from the Bakken correlatives by Gutschick and Rodriguez 1979, fig. 33) or T. montanus from the Madison Group illustrated by Shaw (1962).

Material and Occurrence.--The three most complete specimens are on the same bedding plane in unit 3 of the middle member in NDGS Well No. 8069. One other fragment was found about one foot higher up in the same core, and one small fragment from unit 3 was found in NDGS Well No. 105

#### Unidentified brachiopods

Discussion.--Unidentified brachiopods consist mostly of about 20 minute forms collected or noted from the residues of an acidized core piece from near the base of the middle member in NDGS Well No. 2967. They appear to represent juvenile forms of several species, including orthides, schuchertellids, and productoids. Six of these shells are illustrated on Pl. , fig. 26.

A badly crushed fragment of what may be a punctate brachiopod, as is suggested by its finely granulose surface ornament, was found in unit of the middle member in NDGS Well No. 4958. One small valve from the bottom of the unit 1 in NDGS Well No. 5088 has a shape and size similar to that of pedicle valves of C ornatus, but differs from that species by having coarser costellae (about two per millimetre), greater convexity, and a lack of concentric ornamentation. A small interior of a brachial valve from unit 3 in NDGS Well No. 4340 might be a schuchertellid, as is suggested by its fine costae and wide hingeline; this specimen is about 8 mm wide and 7 mm long.

A few small, costate, weakly convex, and disarticulated rhynchonellid valves that are too incomplete for identification were found near

the base of the lower black shale and in unit 1 of the middle member. The most complete specimen is a pedicle valve from unit 1 in NDGS Well No. 4958; this valve has six costae on one exposed lateral slope and six costae in the sulcus; a total of 14 costae are visible on this shell, which, reconstructed, would be about 9 mm wide, at least 8 mm long, and about 1 mm high. Two very small fragments of costate rhynchonellids from near the base of the lower black shale member in NDGS Well No. 2383 are more finely costate than those from unit 1, with about four costae occurring within one millimetre. The maximum dimension of these costate brachiopods from the lower shale member is about 3 mm.

Phylum MOLLUSCA

Class GASTROPODA

Subclass PROSOBRANCHIA

Order ARCHAEOGASTROPODA

Suborder BELLEROPHONTINA

Superfamily BELLEROPHONTACEA McCoy, 185

Family Bellerophontidae McCoy, 1851

Subfamily Carinaropsinae Ulrich and Scofield, 1897

Genus Phragmosphaera Knight, 1945

Type Species.--P. miranda Knight, 1945 (by original designation).

Diagnosis.--"Coil somewhat reduced, parietal extension plate-like; no longitudinal keel on floor of whorl, ornament fine spiral threads" (Knight, et al., 1960, p. 1180)

Discussion.--Phragmosphaera can be distinguished from similar genera in the family Bellerophontidae by its spiral threads. Within its own subfamily, it differs from Bucanopsis by its greater parietal exten-

sion, and Sphenosphaera lacks spiral threads

Phragmosphaera sp.

Pl. 3, fig.

Discussion.--One faint, fragmented, and flattened mold of an exterior from the lower shale member is assigned to an undetermined species of this genus largely on the basis of the bellerophontid shape very finely reticulated surface ornamentation. The selenizone is poorly preserved across most of the shell and is moderately well preserved within about 2.5 mm of the outer lip. The specimen consists of most of the last whorl and the ornamentation consists of spiral threads intersected by collabral growth lines, both of which average about 10 per millimetre. The shell is very thin and its crushed and distorted condition prevents accurate measurement

Material and Occurrence.--The specimen and its counterpart were taken from near the bottom of the lower black shale in NDGS Well 2383.

Suborder MACLURITINA

Superfamily EUOMPHALACEA Koninck, 1881

Family Euomphalidae Koninck, 1881

Genus Straparollus Montfort, 1810

Type Species.--S. dionysii Montfort, 1810, p. 174 (by original designation).

Diagnosis.--Shells generally trochiform to discoidal; umbilicus wide and phaneromphalous; whorls typically rounded, some angulated or variously shouldered. Slit and selenizone absent; some with faint sinus. Ornamentation usually of transverse growth lines, some with

revolving striae (modified from Shimer and Shrock, 1944, p. 463).

Discussion.--The taxonomy of this genus is somewhat uncertain; Shimer and Shrock 1944, p. 463) stated, "This genus contains many species, especially in the Mississippian and Pennsylvanian, and it seems convenient to arrange them in . . . artificial and intergrading groups, which are treated as subgenera."

Subgenus S. (Straparollus) Knight, 1934

Diagnosis.--"Shell trochiform to discoidal, with deep, moderately wide umbilicus; whorls rounded but with slight shoulder that is locus of very shallow sinus" (Knight, et al., 1960. p. 1192).

S. (Straparollus) sp.

Pl. 3, fig. 3

Discussion.--This uncommon, although locally abundant, form from near the base of the middle member is assigned to a species of S. (Straparollus) on the basis of the low-spired to near-discoidal shape, wide, deep and phaneromphalous umbilical area, and subrounded to rounded whorls. The shells are characterized by their minute size and are preserved as pyrite molds of the interior; no external ornament was seen. Most shells have the apex and (the first?) two to two and one-half whorls preserved; some of the shells appear to be nearly complete. The volutions are adolute and expand rapidly. The largest shell is about 1 mm across its maximum diameter and the other shells range down to a maximum diameter of less than 0.5 mm. The shells are smaller than two small types of gastropods reported from the Louisiana Limestone by Rowley (1908) and Williams (1943) and may be immature or incomplete forms of them. Besides the size, the Bakken specimens differ from the small Louisiana gastropods by having a less pronounced trochiform shape with

less developed shoulders and a wider umbilicus than does Bembexia min-  
and Murchisonia (Murchisonia) pygmaeca is a much more high-spired  
 and slender shell than most of the Bakken specimens. Two of the Bakken  
 specimens, however, are fragments of columellas of relatively high-  
 spired gastropods that may belong to this latter species, but are too  
 fragmental for a more definite identification.

Material and Occurrence.--About 20 specimens were collected or  
 noted from an acidized core piece of silty limestone from near the base  
 of the middle member (unit 1) in NDGS Well No. 2967. An oblique section  
 of another specimen was seen on the surface of a prothyrid pelecypod  
 fragment from near the base of the middle member in NDGS Well No. 8069.

S. (Straparollus) sp. 2

Pl. 3, fig. 4

Discussion.--This species consists of nine poorly preserved  
 and nearly flattened internal molds from the lower shale member that are  
 an order of magnitude in size larger than those assigned to S. (Strapar-  
ollus) sp. 1. Their assignment to the same subgenus is based on their  
 smooth, rounded, and discoidal shape, adovolute form, and the very shal-  
 low sinus that can be clearly seen in some of the specimens. The shells  
 are low-spired and appear similar in size and shape to Plethospira  
socialis from near the base of the Devonian black shales in the eastern  
 United States, but those shells have three rapidly-expanding whorls and  
 those from the Bakken have four whorls. The shells generally appear to  
 be crushed but nearly complete; the largest and best preserved specimen  
 3, fig. 4) has a convexity of about 0.5 mm and a maximum diameter  
 of 9 mm.

Material and Occurrence.--All nine specimens are from within

the basal five feet of the lower shale member in NDGS Well No. 2383.

Order CAENOGASTROPODA

Superfamily LOXONEMATACEA Koken, 1889

Family Loxonematidae Koken, 1889

Genus Loxonema Phillips, 1841

Type Species.--Terebra? sinuosa Sowerby, 1839 (by subsequent designation of King, 1850)

Diagnosis.--Shell relatively large and high-spined with numerous whorls and a deep labral sinus; typically anomphalous; ornament consisting predominantly of collabral growth lines (modified from Knight, et al., 1960, p. 1311; and Shimer and Shrock, 1944, p.

Loxonema cf. L. missouriensis Williams,

Pl. 3, fig. 2

Discussion.--One gastropod fragment from unit 1 of the middle member is tentatively compared to this species on the basis of its relatively large size, apparent high-spined shape, and the ornament of collabral growth lines, which number about 3 per millimetre. The specimen is partly pyritized, somewhat crushed, and deeply imbedded in the matrix. The last whorl and the anterior half of the penultimate whorl are preserved as convex molds of the interior with exterior ornamentation impressed upon them; the posterior half of the penultimate whorl and the next two adapical whorls are preserved as concave molds of the exterior. Specimens of Loxonema from the Louisiana Limestone have been assigned to L. missouriensis Williams (Williams, 1943, p. 103) and although the Bakken specimen appears similar in size, shape, and ornamentation to that species, the poor preservation prevents a positive

assignment.

Material and Occurrence.--The specimen is from the basal foot of the middle member in NDGS Well No. 4958.

#### Indeterminate Gastropod

Discussion.--One gastropod, found in the upper shale member, consists of a basal view of a phaneromphalus shell about 10 mm in maximum diameter. The shell is a faintly preserved and somewhat flattened mold of the interior with faint collabral lines that number about 6 to 8 per millimetre and become more pronounced abapically.

Materials and Occurrence.--The shell is from near the middle of the upper shale member in NDGS Well No. 607

#### Class CEPHALOPODA

#### Subclass NAUTILOIDEA

#### Order ORTHOCERIDA

Discussion.--Orthocerid cephalopods from the Bakken are generally rare and poorly preserved with few if any visible internal structures, and thus their specific, generic, and famillous position are uncertain. Based on the size and shape of the conchs, the specimens appear to belong to either the Orthocerataceae or the Pseudorthocerataceae; these superfamilies are distinguished from each other largely by the characteristics of their siphuncles (Teichert and Moore, 1964, p. K97), and no siphuncles were seen in the Bakken specimens.

#### Orthocerid nautiloid

Pl 3, figs. 7 9

Discussion.--This is an uncommon form from the lower and middle members that is distinguished largely on the basis of the straight

slightly tapering shell and to a lesser extent by the nautiloid suture patterns that are poorly preserved on some of the specimens. The shells are largely fragmental, although one small, complete specimen (Pl. 3, fig. 9) was found in the lower shale member. This specimen has a pyritized phragmocone that contains 13 slightly concave septa spaced about mm apart, and has a relatively long body chamber (larger than the phragmocone) preserved as a flattened, carbonaceous film. This specimen is similar in size and shape to the smallest specimen from the middle mem-

which is missing most of the body chamber and the apical area due to breakage of the core piece; the phragmocone of this specimen is also pyritized and contains 7 sutures spaced about 1 mm apart. Sutures spaced about 2 mm apart are barely visible on a portion of the widest specimen, which is a fragment about 54 mm long and 21 mm wide, and sutures were found on a smaller fragment to be spaced about 3 mm apart. The longest conch (Pl. 3, fig. 7) is a mold of the exterior that has been replaced by pyrite and bornite; it is 65 mm long and its width tapers from 15 mm to about 9 mm. Estimating the shape of the transverse outline of the conchs was not possible due to the crushed and incomplete nature of the material

Material and Occurrence.--Seven conchs are from within the bottom five feet of the middle member in NDGS Well Nos. 607, 2967, 5088, and 8069. The complete specimen is from near the middle of the lower black shale in NDGS Well No. 5088; the counterpart of the phragmocone and the posterior 10 mm of the body chamber of this specimen was also collected. A larger but poorly preserved fragment of what may be a body chamber was found in the basal few feet of the lower shale in NDGS Well



## Order AMMONOIDEA

## Suborder GONIATITINA

## Superfamily CHEILO CERATA CEAE Frech

## Family Cheiloceratidae Frech, 1897

## Subfamily Imitoceratinae Ruzhencev

Genus Imitoceras Schindewolf, 1923

Type Species.--Goniatites rotatorius (Koninck, 1844; by original designaion).

Diagnosis.--A globular to discoidal shell with a closed umbilicus and nonbifurcating, eight-lobed sutures (modified from Miller, et al., 1957, p. L49).

?Imitoceras sp.

Discussion.--One minute and pyritized specimen was found in the insoluble residues of a hydrochloric-acid bath of a core piece taken from unit 1 of the middle member. The specimen is tentatively assigned to a protoconch of an undetermined species of Imitoceras on the basis of its small size, convoluted form, globular shape, and its similarity to protoconchs of an unnamed species of Imitoceras reported from the lower shale of the Exshaw Formation in Alberta by Schindewolf (1959). He identified his specimens largely on the basis of their suture patterns, but no sutures were seen on the Bakken specimen and thus a more definite comparison between the Bakken specimen and those from the Exshaw could not be made. The Bakken specimen was about 1 mm in diameter but it fell apart during curation, and only two fragments that represent about three chambers remain.

Material and Occurrence.--The acidized core piece that yielded this specimen is about four feet from the bottom of the middle member in

NDGS Well No. 2967 this is the same acidized core piece of limestone that yielded the juvenile gastropods and many of the juvenile brachiopods.

### Indeterminate coiled cephalopod

#### Pl. 3, fig. 8

Discussion.--Two fragments of coiled cephalopod whorls were found on bedding planes near the bottom of the lower shale member. Suture patterns were not preserved and thus it could not be determined in which order of cephalopods to place them. The shells are preserved as faint and poorly preserved casts(?) or molds of the exterior. One specimen (Pl. 3, fig. 8) consists of about 90 degrees of a volution; the umbilical shoulder shows eight weak ribs that die out toward the venter. The curvature of this specimen is hard to determine because of the matrix adhering to the dorsum. This specimen is about 15 mm long and is 10 mm wide. A much smaller specimen from nearby in the same core is a mold of the exterior of the area near the umbilical region of a similarly ornamented cephalopod. This smaller specimen represents close to 180 degrees of an early whorl and what appears to be part of an open umbilicus. The whorl has nine slightly curved ribs spaced about one millimetre from each other and is about 2 mm wide and has a diameter of about 4 mm. The fragments appear the most similar to ammonoids placed in Platyclemania, but that genus is restricted to the Platyclemania zone of middle Famennian age (House, 1962, p. 25

Material and Occurrence.--Both fragments are from the bottom five feet of the lower shale member in NDGS Well No. 2383. Most of the counterpart of the larger specimen was also collected.

## Class PELECYPODA

Discussion.--Pelecypods were found to be rare, fragmentary, and generally poorly preserved in the Bakken Formation. Many of the structures needed for generic and specific identification, such as the hinge structure, ornamentation, muscle scars, and original shape, are generally poorly preserved or absent and thus generic and specific identifications were not possible.

### Fragmentary pelecypods

Pl. 3, figs. 5, 6

Discussion.--Seven moderately well-preserved pelecypods were found in the basal three feet of the middle member that may represent four species. Five partly pyritized but remarkably preserved shells of one species appear similar in general shape and strong concentric ornamentation to Grammysia hannibalensis from the Louisiana Limestone (Williams, 1943), but are much smaller; the largest of these specimens from the Bakken (Pl. 3, fig. 6) is about 5 mm long and appears to have a height of about 3 mm, although its dorsal margin is encased in matrix. One equally small and pyritized pelecypod was found on the same bedding plane as one of these "grammysians", but it differs from them primarily by its more centrally located beak.

The largest pelecypod found is the anterior portion of a disarticulated shell from unit of the middle member (Pl. 3, fig. 5). This shell may belong to a species of Prothyris, as suggested by its size, elongate shape, anteriorly placed beak, and weak and concentric lines on the shell. The specimen is stained brown and is a fragmental mold of an interior that has ten concentric and faint lines spaced about 1 mm apart over its surface. This fragment is some 20 mm long and about 9 mm high,

and much of the shell is encased in matrix.

The poorest preserved pelecypods of the Bakken consist of three disarticulated and fragmental valves from near the bottom of the lower shale member and one nearly complete valve from unit 3. One of the valves from the lower shale is a mold of an exterior with poorly preserved concentric lines over most of the surface. This fragment is too incomplete for measurement, but it has an estimated reconstructed length of about 20 mm. The other two valves from the lower shale are rather featureless molds of the interior; one of these is about 3 mm long and 2 mm high and exhibits a few very faint growth lines; the other is about 11 mm long and 10 mm high and shows the beak indistinctly. The valve from unit 3 is a poorly preserved exterior with an ovate shape and several faint concentric lines near the ventral margin. This specimen is about 20 mm long and 16 mm high, and is very thin, with a width of about 2 mm.

Material and Occurrence.--The pelecypods from the lower shale member are all from near the base of that member in NDGS Well No. 2383. All except one of the pelecypods from the middle member are from near the base of unit 1 in NDGS Well Nos. 4340 and 5088. The poorly preserved specimen from unit 3 was found in NDGS Well No.

Phylum ARTHROPODA

Superclass CRUSTACEA

Class TRILOBITA

Order PTYCHOPARIIDA

Suborder ILLAENINA

Superfamily PROETACEA Salter, 1864

Family Brachymetopidae Prantl and Přibyl, 1950

Genus Brachymetopus McCoy, 1847

Type Species.--B. strzeleckii (by subsequent designation of Reed, 1903).

Diagnosis.--"Cephalon with raised border and distinct border furrow; . . . . Pygidium half-circle or longer; axis about 0.3 of width of pygidium, with 9 to 17 rings; pleurae gently curved backward, divided by longitudinal furrows into a narrow anterior strip and a raised, broader posterior ridge" (Moore, 1959, p. 0408)

Subgenus B. (Brachymetopus) McCoy, 1847

Diagnosis.--"Axis of pygidium with 9 to 10 segments; posterior ridges of pygidial pleurae prolonged beyond thickened border into spines curved backward and bearing large tubercle where they cross border" (Moore, 1959, p. 0408).

B. (Brachymetopus) sp.

Pl. 3, fig. 14

Discussion.--A minute pygidium of a trilobite was recovered from a partly acidized core piece from unit 3 of the middle member. This specimen is about 1 mm high and 1 mm long but the diagnostic features of this Lower Mississippian subgenus (in North America) are finely preserved. The specimen has about nine pygidial segments, a prominent highly convex axial lobe, and gently convex pleural lobes. Each pleural lobe of a segment has five more or less regularly arranged rows of tubercles that generally increase in size anteriorly; these tubercles appear to be of variable height but this may be due to the possibility of their tips being broken off. The axial lobe has seven regularly arranged rows of tubercles on each segment, with the medial row containing the largest tubercles. Portions of the margin are visible under

high magnification (X54) on both sides of the pygidium and show the thickened border, the pleural spines, and the large tubercles where the pleural spines cross the border

Material and Occurrence.--The trilobite was found on a bedding plane of calcareous siltstone that contains a fossil hash of small chonetid valves, spines, and disarticulated pelmatozoan columnals. This core piece is from near the top of unit 3 in NDGS Well No. 8069.

Class BRANCHIOPODA

Subclass DIPLOSTRACA

Order CONCHOSTRACA

Suborder SPINICAUDATA

Superfamily CYZICOIDEA Stebbing, 1910

Family Cyzicidae Stebbing, 1910

Genus Cyzicus Audouin, 1837

Type Species.--Limnadia tetracera Krynicki, 1830, p. 76 (by original designation).

Diagnosis.--At the generic level the diagnosis of these bivalved branchiopods is based on soft-part morphology. Tasch 1969, p. R151 has diagnosed this genus as, "Rostrum of male broadly spatulate in profile; rostrum of female terminating acutely; flagella of antennae with 16 to 22 segments

Subgenus C. (Lioestheria) Depéret and Mazeran, 1912

Type Species.--Estheria (Lioestheria) lallyensis Depéret and Mazeran, 1912, p. 167 (by original designation)

Diagnosis.--Carapace with thin, variably-shaped valves covered with numerous concentric growth lines; intervalles with punctate and

granulate or hachured micro-ornamentation. Hingeline straight and lacking teeth (modified from Tasch, 1969, p. R151)

Discussion.--Tasch 1963, p. 1243) wrote that "the subgeneric designations Euestheria and Lioestheria refer to valves bearing polygonal as contrasted with punctate or hachured ornamentation." The micro-ornamentation was not seen on the Bakken specimens, however. The Bakken forms are assigned to this subgenus on the basis of their close resemblance to a form of C. (Lioestheria) from the black shale members of the immediate Bakken correlatives in the Western Interior. (Gutschick and Rodriguez, 1979, p. 50).

Cyzicus (Lioestheria) sp

Pl. 3, figs. 10-13, 18

Discussion.--Numerous valves from the Bakken Formation closely resemble an unnamed species of C. (Lioestheria) from the Bakken correlatives in the Western Interior that was first illustrated by Gutschick et al. (1962). As in those specimens, the Bakken valves are mostly disarticulated, lie flat on bedding planes, and are commonly prolific in the top few inches of the lower shale member. The specimens from the Bakken are typically somewhat crushed and fragmental and many are of a very small size. The valves are slightly convex and typically ovate with a nearly straight hingeline, a gently rounded ventral margin, a broadly curved anterior margin, and a sharply curved posterior margin. The number of growth lines is usually greater than 10 per millimetre but this can be variable, as some, especially the larger valves, may have only about two rugosic growth lines per millimetre in the umbonal region. Another variable feature in the specimens is the location of the beak, which is positioned more anteriorly in some specimens than in

others. This appears to be more related to size, as it was seen mostly in the larger valves, than to sexual dimorphism, which Tasch 1969b, p R144) reported is developed in many conchostracans. A large range was seen in the size of the valves; large valves are about 12 mm long and 9 mm high and the smallest are about 3 mm long and 2 mm high. One right valve of unusually large size (Pl. 3, fig. 11 was collected from near the base of the lower shale member by Timothy P. Huber; this specimen is about 21 mm long, 15 mm long along the hingeline, and about 10 mm high

Material and Occurrence.---This species is locally abundant in the bottom five feet of the lower shale member, where it was found in NDGS Well Nos. 607, 2383, and 5088. The species also occurs within about the top six inches of the lower member, where prolific valves of this species mark a persistent biosome in the central portion of the basin; this conchostracan bed was found in NDGS Well Nos. 413, 1202 2820, 2967, 3167, 4340, and 5088. Fifteen valves were found in the upper shale member and these appear identical to the valves from the lower shale; these were found in NDGS Well Nos. 607, 4297, 5088, 7887, and 8474. A single disarticulated and unflattened valve was found near the bottom of the middle member in NDGS Well No. 5088. The matrix of this specimen is a dark-brown argillaceous siltstone that appears transitional between light-gray siltstone above it and black shale below it. This transitional rock and its close proximity to the lower shale member suggests that the valve may have been reworked from the top of the lower shale member, but other fossils on the same core fragment (Orbinaria pyxidata, and coarsely capillate brachiopod fragments) do not support this.

The occurrence of this species near the base of the lower shale



member and in the upper shale member appear to mark a stratigraphic extension of this very late Devonian to early Mississippian species; and its occurrence near the base of the lower shale member appears to mark an extension of its age. Cyzicus lioestheria sp. has not been reported to occur in rocks older than the Middle Bispathodus costatus conodont Biozone (of very late Devonian age) but Hayes (1984) determined that the age of the lower shale member in North Dakota probably dates back to the Polygnathus styriacus Biozone, which is slightly older than the Middle B. costatus Biozone (see Figure 4 of text).

#### Class MALACOSTRACA

#### Subclass EUMALACOSTRACA

#### Indeterminate eumalacostracan

#### Pl. 3, fig. 15

Discussion.--A flattened carbonaceous impression of the right side of the posterior portion of a shrimp-like organism was found near the top of the lower shale member. The anterior portion of the specimen was cut away by the core barrel and the specimen consists of six abdominal somites and the posterior 5 mm of a badly crushed carapace. The general area of the telson can be seen but uropods and the telson are not preserved. The specimen has a height of about 7 mm and a length of about 27 mm, with the telson area being about 10 mm long.

Comparison.--The incompleteness of the Bakken specimen, especially the absence of the cephalothorax region, prevents the placement of the Bakken specimen into a superorder of the Eumalacostraca. Schram (1969, table reported that the only families of the Eumalacostraca that date back to the Devonian are the Eocarididae and Palaeopalaemoni-

dae of the order Eocarida. The Bakken specimen differs from both of these families by having truncated pleural lobes on the abdominal tergites, whereas forms in the Eocarididae have pointed pleural lobes and those of the Palaeopalamonidae have rounded pleural lobes. Truncated pleural lobes appear to be more characteristic of Archaeocaris (Brooks, 1969, p. R535) of the superorder Hoplocarida, but the Bakken specimen does not show the characteristic spine and furca of this superorder which is not known to occur in rocks older than the Early Mississippian (Schram, 1969, table

Material and Occurrence.--The specimen is from within the top few inches of the lower shale member in NDGS Well No. 5088. The counterpart, which is missing the telson area, was also collected

#### Indeterminate arthropod fragments

Discussion.--Nonbrachiopod macrofossils of uncertain affinity from the Bakken mostly appear to be arthropod fragments. Three specimens might represent hypostome fragments of trilobites and one specimen appears to be a single disarticulated pleuron of a trilobite. This pleuron has a smooth surface and is much larger (about 6 mm long) than the minute, tuberculate trilobite pygidium from unit 3 here assigned to Brachymetopus (Brachymetopus) sp

Large, relatively featureless, ostracod-like valves of unknown affinity are fairly common throughout most of the lower black shale member and one specimen was found in the upper shale member. These valves lie flat on bedding planes, are slightly crushed, commonly pyritized and are mostly articulated along the hingeline or have slipped slightly past each other. Left and right valves are of nearly the same size and each has a nearly straight hingeline and ventral margin and sharply

rounded anterior and posterior margins. The valves are typically about 6 mm long and about 2 to 3 mm high, although some are about one-half this size. Ostracods of this large of a size were reported by Scott (1961, p. Q103) to be characteristic of the order Leperditicopoda, but the Bakken specimens differ from the leperditicopides by the equal size of the left and right valves and by the straight and parallel dorsal and ventral margins

Material and Occurrence.--Two of the possible trilobite hypostomes were found in unit 1 in NDGS Well Nos. 4340 and 4958; the third possible hypostome is from near the base of the lower black shale in Well No. 5088. The possible pleuron of a trilobite was found in 3 in NDGS Well No. 4958. The ostracod-like valves are from mostly near the middle of the lower shale member, where few other macrofossils were found. These valves were noted in NDGS Well Nos. 607, 1748, 3363, 4264, 4340, and were especieally common in NDGS Well No. 5088.

#### Phylum ECHINODERMATA

##### Pelmatozoan echinoderm

##### Unidentifiable pelmatozoan column fragments

Discussion.--Fragments of pelmatozoan columns were rarely found in the Bakken middle and upper shale members. The fragments are generally poorly preserved and are mostly single columnals. They have a circular cross-section and are from 0.5 to 5.0 mm in diameter. The most complete pleuricolumnal is 19 mm long, has 7 articulated columnals, and has a diameter of about 3 mm.

Material and Occurrence.--Eleven specimens were found in units 2 and 3 of the middle member. Five of these specimens are disarticu-

lated columnals from acidized pieces of calcareous siltstone from within the top two feet of unit 3 in NDGS Well Nos. 105 and 8069, and the other specimens from the middle member are mostly articulated fragments of the column from the bottom six feet of unit 1 in NDGS Well Nos. 2967, 4340, 4508, 4958, 5088, and 8069. Specimens from the upper shale member consist of a number of very small (0.5 to 1 mm in diameter) and disarticulated columnals scattered over a bedding plane that contains Orbiculoidea limata and the indeterminate gastropod from near the middle of the upper member in NDGS Well No. 607.

Phylum CHORDATA

Class PISCES

Fossil fish fragments

Pl. 3, fig. 17

Discussion.--Traces of fossil fish were found rarely throughout the black shale members of the Bakken and are mostly small fragments of scales, teeth, and bones that are commonly associated with concentrations of conodonts (Hayes, 1984, p. 56-59). Four complete or nearly complete fish scales were found on bedding planes in the lower shale member in NDGS Well No. 607. Three of these scales are relatively large carbonaceous impressions that appear similar in size, shape, and ornamentation to crossopterygian scales from the Tyler Formation (Pennsylvanian) of North Dakota illustrated by Grenda (1977, pl. 21, figs. 6, 7). The Bakken scales are not well preserved, but an ornament of fine concentric lines that number about 4 per millimetre cover the surface. One of these scales is too fragmental for measurement and the largest and most complete one (Pl. 3, fig. 17) is about 20 mm high and 23 mm long.

---

The fourth specimen, much smaller, is a well preserved fragment that resembles palaeoniscoid fish scales from the Tyler Formation of North Dakota (Grenda, 1977, pl. 21, fig. 8). The Bakken specimen is nearly complete, although its posterior margin is broken away. It differs somewhat from Grenda's specimens by having its concentric ornamentation extend across all but the posterior edge of the scale, whereas Grenda's specimens have no ornamentation over the posterior one-half. Perhaps this difference is caused by the breakage in the Bakken specimen. Both the *Crossopterygii* and the *Palaeoniscoidea* are primitive bony fish that extend back to the middle Devonian (Romer, 1945, p. 89)

#### PLANTAE

Discussion.---Although plant fossils were found to be generally rare in the Bakken, they are locally numerous and represent several different forms. They are preserved mostly as inconspicuous carbonaceous impressions and most were found to be restricted to certain stratigraphic intervals of the Bakken

In the lower shale member, numerous thalli of *Foerstia* sp. (Pl. 3 figs. 16, 19) occur over about a three-foot interval starting about 10 feet above the base of the 45-foot-thick lower shale member in NDGS Well No. 4340. The thalli of this supposed form of pelagic alga (Mathews 1983, p. 327) are preserved as inconspicuous carbonaceous impressions that are recognized largely by their small size and ovate to bilobed or bifurcating shape; the cancellate surface pattern is poorly preserved on a few specimens. No attachment structures were seen. Many of thalli are shredded fragments. The largest specimens are about 6 mm wide and 7 mm long; the smallest complete thallus is about 3 mm wide and long.

Tasmanitid spore cases were found to be locally abundant in the lower and upper shale members. Most of these are carbonaceous or asphaltic compressions but some are pyritic or amber-colored and a few are uncrushed; amber-colored samples about 0.2 mm in diameter were collected from the basal foot of the lower black shale in NDGS Well No. 5088.

Other plants from the lower shale member consist of two stemlike structures from near the middle of the lower shale member in NDGS Well 2828 and 4340. These "stems" are straight, nonbranching structures from 7 and 9 mm wide and have a relief of up to about 3 mm. The largest of these is an 87-mm long impression and the other is a partly crushed and partly pyritized compression; both lie flat on bedding planes and extend from one end of the core piece to the other.

Plant fossils from the middle member include small twiglike structures that are scattered throughout unit 1; these appear to be especially common in the upper one-half of this unit. These "twigs" are carbonaceous or pyritic compressions that commonly bend and bifurcate; large specimens are up to about 6 mm long and 0.2 mm wide. Carbonaceous impressions of long blade-like "leaves" (Pl. 4, fig. 7) are common in the basal few feet of unit 2 of the middle member but are typically inconspicuous due to poor preservation. These plants are abundant in cores from near the center of basin and seem to form a laterally persistent biosome in that area (NDGS Well Nos. 413, 1202, 1405, 2967, 3167, and 5088) but are absent elsewhere. No surface pattern on these leaves could be seen, although what appears to be a midrib is visible on one specimen. The largest leaves from the base of unit 2 are 3 mm to 4 mm wide and many extend across the core pieces, a distance of up to over

100 mm. Smaller leaves and leaf fragments are common in this interval; these are less than 20 mm long and are about 1 to 2 mm wide. These plants in the Bakken closely resemble blade-like "leaves" reported by Conkin and Conkin 1973, p. 25) to occur at and near the base of Horton Creek Member of the Hannibal Shale in western Illinois; these plants have an average width of 2 mm and are up to 90 mm long; Conkin and Conkin 1973) said that their plants are probably thallophytes

Other plant fossils of the middle member consist of one possible fragment of a stem from near the base of unit 1 in NDGS Well No that is pyritized, about 65 mm long, and .7 mm wide and four stemlike structures, three of which are on one bedding plane (Pl. 2, fig. 17) from near the top of unit 2 in NDGS Well Nos. 7851 and 8069. These structures are partly crushed compressions that resemble the stemlike compression from the lower shale member.

The only plant remains found in the upper shale are local concentrations of tasmanitid spore cases and one carbonaceous compression of what appears to be a vascular land plant (Pl. 4, Fig. 1 collected from NDGS Well No. 8177 by Webster 1982). This plant lies flat on a bedding plane and extends across the core piece; it appears to be a flattened piece of a reed or stem but shows none of the surface texture or leaf material and could not be identified

#### TRACE FOSSILS

Ichnogenus Chondrites Sternberg, 1833

Type Species.--Fucoides lycopodiodes Brongniart, 1828, p. 72 (by subsequent designation of Andrews, 1955, p. 127).

Diagnosis.--A "form genus" of small, cylindrical and branching tunnels forming plantlike dendritic patterns; a system consists of one

or a few vertical tunnels that branch and become horizontal distally; the tunnels of a single system do not cross or penetrate one another. Tunnels in the same system are typically of a constant diameter that is between 0.5 and 5.0 mm. The branching may be regular or irregular; the angle of branching is between 25 and 40 degrees and may be fixed or variable (modified from Häntzschel, 1975, p. W50).

Chondrites sp

Pl. 4, fig. 4

Description.--Networks of numerous branching tunnels that appear similar to forms from the Western Interior region, assigned to Chondrites by Gutschick and Rodriguez (1977, p. 200), were found on bedding planes in sandy intervals of the middle member in two cores. The tunnels are preserved in convex epirelief and lie on top or underneath one another; many bifurcate or have multiple branching; the angle of bifurcation ranges from about 30 to 45 degrees. The tunnels are horizontal and are up to about 20 mm long and range from about 1 to 3 mm in diameter, with most having a diameter of about 2 mm.

Material and Occurrence.--Specimens were collected from a two-foot-thick interval from near the bottom of unit 2 of the middle member in NDGS Well No. 2967. This interval consists of dark gray, slightly calcareous, and very fine-grained sandstone that is interlaminated with light gray, nonfossiliferous, calcareous, and fine-grained sandstone. The form was also noted in a sandy interval a few inches thick from near the top of unit 2 in NDGS Well No. 5088.



Ichnogenus Cosmoraphe (sensu Rodriguez and Gutschick, 1977)

Cosmoraphe? sp. Rodriguez and Gutschick, 1970, p. 414, pl. 6, fig. a.

Cosmoraphe sp. Gutschick and Rodriguez, 1977, p. 198.

Diagnosis.--Small, simple, and smooth meanders of regular size that are not physically close to each other; commonly in 2 orders of size (modified from Häntzschel, 1975, p. W53; and Rodriguez and Gutschick, 1970, p. 425).

Cosmoraphe sp.

Pl. 4, fig. 6

Discussion.--This is a common form from unit 1 of the middle member that consists of very small meandering and horizontal endichnial traces that are very regular and appear identical in size and shape to an unnamed species of Cosmoraphe from siltstone in the Sappington Member of the Three Forks that was illustrated (but not described) by Rodriguez and Gutschick 1970, pl. 6, fig. 6A) who, at the time, questioned the generic assignment of this form. The meanders are simple, flattened, and smooth with a maximum width of about 0.8 mm and a maximum length of about 9 mm.

Material and Occurrence.--The traces are preserved in the non-laminated siltstones of unit of the middle member and are most common in the upper one-half of the unit, where they are closely associated with the trace fossil Scalarituba missouriensis Weller. Samples of Cosmoraphe were collected from NDGS Well Nos. 4340, 4958, and 5088.

Ichnogenus Planolites Nicholson, 1873

Type Species.--P. vulgaris Nicholson and Hinde, 1875, p. 139 by subsequent designation of Howell, 1943, p. 17).

Diagnosis.--"Cylindrical or subcylindrical infilled burrows (diameter up to 15 mm), straight to gently curved, nonbranching; usually more or less horizontal or oblique to bedding planes, penetrating sediment in irregular course and direction, may cross one another" (Häntzschel, 1975, p. W95).

Planolites sp.

Pl. 4, fig. 2

Discussion.--This form is represented by three simple and smooth horizontal or vertical endichnial burrows found in unit of the middle member. The burrows are pyritized and straight to slightly curved. One specimen is vertical and the other two, one of which appears to taper, lie flat on bedding planes. The burrows are from about 2 to 4 mm wide and are about 30 to 70 mm long.

Material and Occurrence.--The two horizontal specimens are from near the middle of unit 1 of the middle member in NDGS Well Nos 607 and 4340, and the vertical specimen is from near the top of unit 1 in NDGS Well No. 5088

Ichnogenus Scalarituba Weller, 1899

Type Species.--S. missouriensis Weller, 1899, p. 12, (by original designation).

Diagnosis.--"Subcylindrical burrows, 2 to 10 mm (max. in diameter; sinuous; parallel, oblique or nearly vertical to bedding; marked by transverse 'scalariform' ridges situated at average distances of 2 to 3 mm, which may be only poorly preserved or lacking in argillaceous rocks" (Häntzschel, 1975, p. W103)

Scalarituba missouriensis Weller, 1899

Pl. 4, fig. 8

S. missouriensis Weller, 1899, p. 12, pl. 16, fig. 1; Branson, 1938, p. 14-15, pl. 20, fig. 28; Conkin and Conkin, 1968, p. 3-4, pl. 1-4; Rodriguez and Gutschick, 1970, p. 419-420, pl. 6A; Häntzschel, 1975, fig. 65: 4; Hakes, 1976, p. 33, pl. 10, fig. 3

Diagnosis.--Same as for the genus (Häntzschel, 1975, p. W103-W105.

Discussion.--This is a common form from unit that, where well preserved, appears identical to this rather distinctive ichnospecies. Transverse ridges of the backfilling ("scalariform ridges" of Conkin and Conkin, 1968, p. 2) are moderately to poorly preserved; this preservation appears to depend on the matrix, as the traces are not well preserved where the rock is argillaceous. The traces are slightly to notably curved and are nonbifurcating endichnial burrows that are slightly convex or flattened. The burrows are small to fairly large and, in proportion to the size of the burrow, the ridges are spaced about 2 to 5 mm apart. The largest specimen (Pl. 4, fig. 8) is about 100 mm long (although part of it has been cut away by the core barrel) and 6 mm wide. The smallest specimen with clearly defined ridges is about 10 mm long and 2 mm wide.

Material and Occurrence.--This form is rare to abundant throughout the siltstones of unit 1 of the middle member and is especially common in the heavily bioturbated upper half of unit 1. Samples were collected or noted from NDGS Well Nos. 413, 607, 2618, 2967, 3167, 4340, 5088, and 7851

## Ichnofossil, genus and species indeterminate

Pl. 4, fig. 5

Discussion.--One small and asphaltic structure was found on a bedding plane in the lower shale member that consists of two sets of closely spaced, sub-parallel, concentric, and transverse ridges. The ridges appear somewhat similar in size and shape to those of Spirophyton but are not as regularly concentric. This specimen might represent a non-biogenetic asphaltic structure; such structures are fairly common in the lower shale member and occur in a variety of shapes and sizes. The largest and most complete set of ridges on the specimen at hand has about 10 ridges preserved; the largest of these ridges has a diameter of about 7 mm.

Material and Occurrence.--The specimen is from about 7 feet from the bottom of the lower shale member in NDGS Well No. 2226.

## EXPLANATION OF PLATE 1

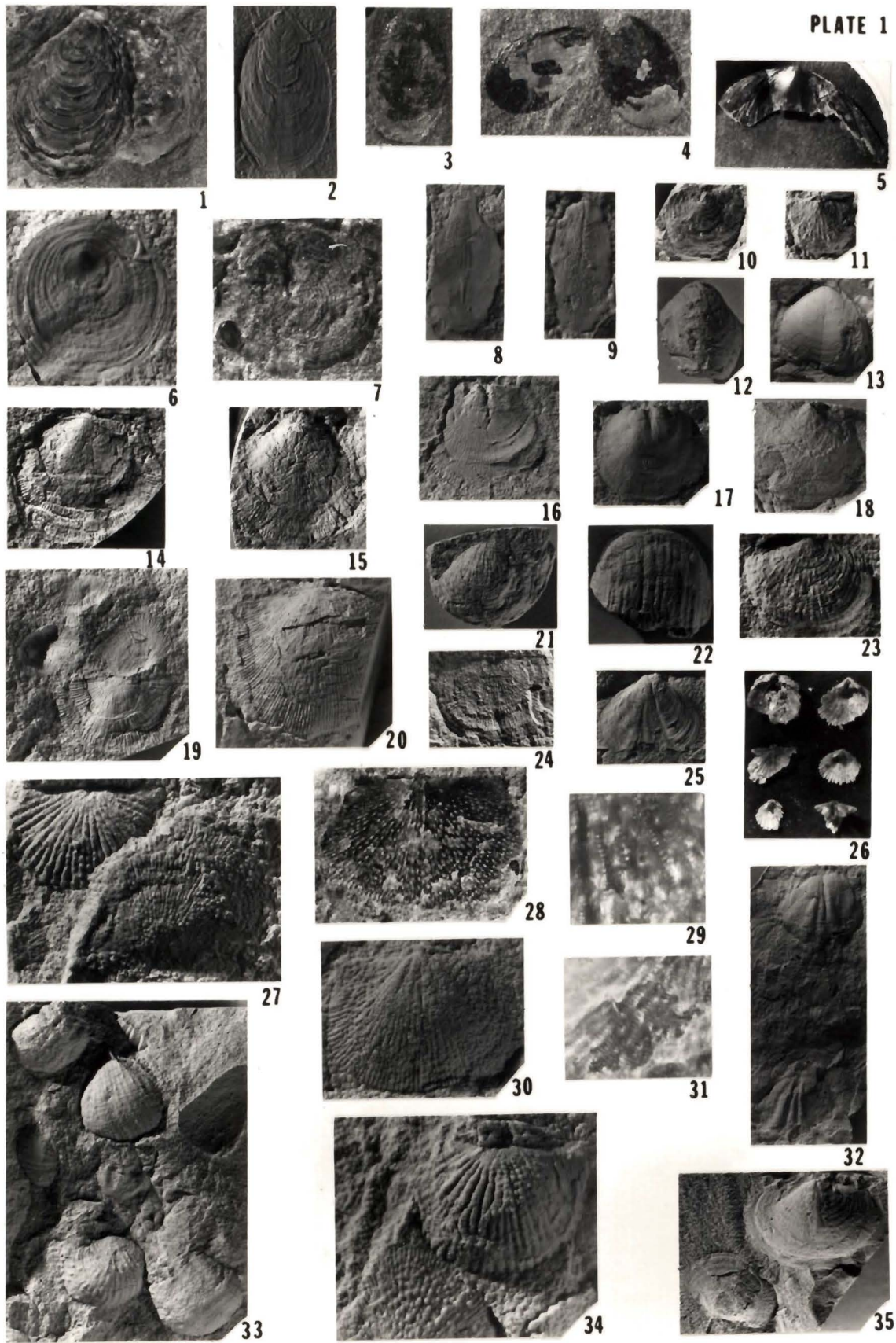
All figures X1 unless otherwise indicated.

## Figure

- 1      Lingula sp. 4. Two nearly-articulated valves, X3.4, unit 1, NDGS Well No. 8069, UND 2735.
- 2      Lingula sp. 1. X5, upper shale member, NDGS Well No. 5088 UND 2731.
- 3, 4    Lingula sp. 2. 3. X4, lower shale member, NDGS Well No. 607, UND 2732. 4. Two valves slipped past one another, X6 lower shale member, NDGS Well No. 607, UND 2733.
- 5      Lingula sp. 3. Phosphatic valve from a bleached core piece, X3, lower shale member, NDGS Well No. 5088, UND 2734.
- 6, 7    Orbiculoidea limata Rowley. 6. Brachial valve, X3, unit 3, NDGS Well No. 8069, UND 2739. 7. Pedicle valve, X3.5, unit 1, NDGS Well No. 4958, UND 2738.
- 8, 9    Barroisella sp. 8. Mold of the interior of a brachial valve, X4, lower shale member, NDGS Well No. 2383, UND 2736. 9. Mold of the interior of a pedicle (?) valve, X4, lower shale member, NDGS Well No. 2383, UND 2737.
- 10, 11   Orbinaria pyxidata (Hall). 10. Brachial valve, unit 3, NDGS Well No. 2967, UND 2756. 11. Brachial valve, unit 3, NDGS Well No. 2967, UND 2757.
- 12      Composita sp. 1. Articulated specimen in dorsal aspect, unit 3, NDGS Well No. 4340, UND 2765.
- 13      Composita sp. 2. Pedicle valve, unit 3, NDGS Well No. 2618, UND 2766.
- 14-18   Rhipidomella missouriensis (Swallow). 14. Decorticated brachial valve, unit 1, NDGS Well No. 4958, UND 2740. 15. Exterior of pedicle valve, unit 1, NDGS Well No. 3167, UND 2741. 16. Rubber mold of the interior of a brachial valve (UND 2742.), unit 1, NDGS Well No. 2967. 17. Rubber mold of the interior of a brachial valve (UND 2743.), unit 1, NDGS Well No. 2967. 18. Partly decorticated pedicle valve, unit 3, NDGS Well No. 8069, UND 2744.
- 19      Schuchertella lens (White). The valves nearest the bottom and left margins are pedicle valves and the other two are interiors of brachial valves, unit 1, NDGS Well No. 8069, UND 2746.
- 20      Schellweinella inflata (White and Whitfield). Brachial valve, unit 1, NDGS Well No. 1405, UND 2745.
- 21-23, 33   Rhytiophora arcuatus (Hall). 21, 22. Posterior and anterior views, respectively, of a crushed pedicle valve, unit 1, NDGS

- Well No. 8069, UND 2758. 23. Interior of a brachial valve showing auricle, unit 1, NDGS Well No. 8069, UND 2759. 33. One valve in the lower one-half of the photograph is the interior of a brachial valve and the others are poorly preserved exteriors of pedicle valves, unit 3, NDGS Well No. 8069, UND 2760.
- 24      Rugosochonetes sp. Brachial valve, X2, unit 3, NDGS Well No. 8069, UND 2755.
- 25, 32    Rugaltarostrum madisonense (Haynes). 25. Pedicle valve, lower shale member, NDGS Well No. 2383, UND 2761. 32. Rubber cast of two brachial valves made from a natural mold of the exteriors (UND 2762.), lower shale member, NDGS Well No. 1679.
- 26      Minute, unidentified brachiopods. Interiors of silicified valves from a hydrochloric acid bath, X3, unit 1, NDGS Well No. 2967, UND 2780.
- 27, 28, 30, 31, 34    Chonetes gregarius Weller. 27 (lower right). Mold of the interior of a brachial valve, X5, unit 3, NDGS Well No. 4958, UND 2750. (upper left is C. ornatus, UND 2751.). 28. Interior of a brachial valve, X5, unit 3, NDGS Well No. 4958, UND 2747. 30. Mold of the interior of a pedicle valve, X5, unit 3, NDGS Well No. 4958, UND 2748. 31. Micro-ornament of a brachial valve, X15, unit 3, NDGS Well No. 105, UND 2749. 34 (lower left). Anterior portion of a brachial valve, X5, unit 3, NDGS No. 8069, UND 2752. (upper right is C. ornatus, UND 2753.).
- 27, 29, 34    Chonetes ornatus Shumard. 27 (upper left). Mold of the exterior of a brachial valve, X5, unit 3, NDGS Well No. 8069, UND 2751. (lower right is C. gregarius, UND 2750.). 29. Micro-ornament of pedicle valve, X15, unit 3, NDGS Well No. 105, UND 2754. 34 (upper right). Decorticated pedicle valve, X5, unit 3, NDGS Well No. 8069, UND 2753. (lower left is C. gregarius, UND 2752.).
- 35      Torynifer sp. Interiors of two brachial valves, unit 3, NDGS 8069, UND 2779.

PLATE 1



## EXPLANATION OF PLATE 2

All figures X1 unless otherwise indicated.

## Figure

- 1-3 valve Spirifer greenockensis Brown. 1. Partly decorticated pedicle unit 3, NDGS Well No. 4958, UND 2775. 2. Exterior of brachial valve and interarea, unit 3, NDGS Well No. 4958, UND 2776. 3. Rubber cast of a brachial valve made from the counterpart (UND 2777.) of UND 2776.
- 4 ?Paraconularia missouriensis (Swallow). X5, upper shale member or Carrington shale facies of the Lodgepole Formation, NDGS Well No. 207, UND 2729.
- 5 6 Syringothyris halli Winchell. 5. Rubber mold of an interior of a pedicle valve (UND 2774), unit 3, NDGS Well No. 8069. 6 (upper part). Partial mold of an articulated interarea showing a portion of the syrinx; (lower part), fragment of the exterior of a brachial valve, unit 3, NDGS Well No. 4958, UND 2773.
- 7, 8, 13, 15 Syringothyris hannibalensis (Swallow). 7. Decorticated exterior of a brachial valve, unit 1, NDGS Well No. 3167, UND 2769. 8. Exterior of an incomplete interarea of a pedicle valve showing part of the vertically striated perideltidium, unit 1, NDGS Well No. 607, UND 2770. 13. A partly decorticated brachial valve and broken posterior of the pedicle valve showing the dental lamellae and an oblique cross section of the syrinx, unit 1, NDGS Well No. 5088, UND 2771. 15. A partly decorticated brachial valve and broken posterior of the pedicle valve; a small rhynchonellid is in the broken umbonal area, unit 1, NDGS Well No. 8069, UND 2772.
- 9, 10 Tylothyris clarksvillensis (Winchell). 9. Small brachial valve, unit 1, NDGS Well No. 4340, UND 2767. 10. Pedicle valve, unit 1, NDGS Well No. 2967, UND 2768.
- 11 ?Allorhynchus acutiplicum Weller. Exterior of pedicle valve, unit 3, NDGS Well No. 607, UND 2764.
- 12 ?A. heteropsis (Winchell). Disarticulated valves with a poorly preserved productid near the center of the core piece, unit 3, NDGS Well No. 8177, UND 2763.
- 14 Syringopora sp. morphogroup C of Sando, 1984. Unit 2, NDGS Well No. 527, UND 2730.
- 16 Spirifer sp. Concentration of disarticulated valves, some of which may belong to S. greenockensis. One fragment of a brachial valve of Syringothyris halli occurs above the Spirifer in the center, unit 3, NDGS Well No. 4958, UND 2778.
- 17 Three fragments of possible plant stems. Unit 2, NDGS Well No. 7851, UND 4346.



PLATE 2



1



2



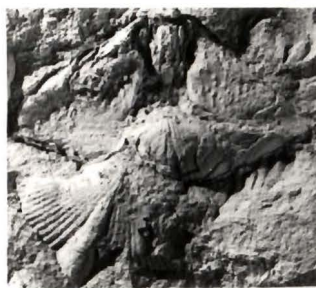
3



4



5



6



7



8



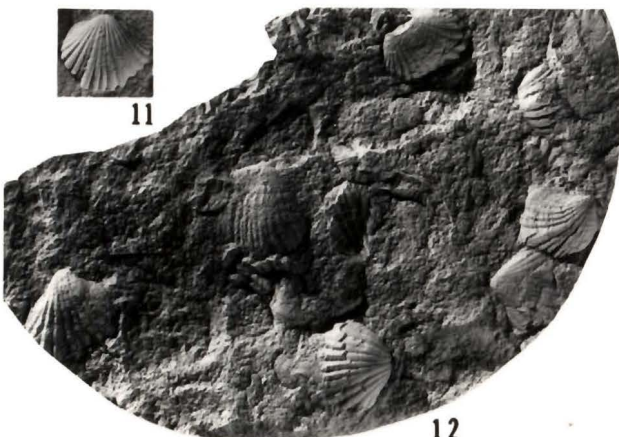
9



10



11



12



13



14



15



16



17

## EXPLANATION OF PLATE 3

All figures X1 unless otherwise indicated.

Figure

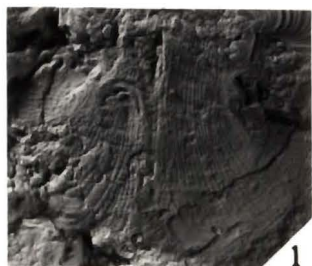
- Phragmosphaera sp. X3, lower black shale, NDGS Well No. 2383, UND 2781.
- 2 Loxonema cf. L. missouriensis Williams. X3, unit 1, NDGS Well No. 4958, UND 2784.
- 3 Straparollus (Straparollus) sp. 1. Pyritized molds from a hydrochloric acid bath, X3, unit 1, NDGS Well No. 4958, UND 2782.
- 4 S. (Straparollus) sp. 2. Lower shale member, NDGS Well No. 2383, UND 2783.
- 5 Prothyrid pelecypod. Anterior part of shell, unit 1, NDGS Well No. 8069, UND 2788.
- 6 Grammysian pelecypod. Ventral view, X4, unit 1, NDGS Well No. 4340, UND 2789.
- 7, 9 Orthocerid nautiloid. 7. Portion of a conch partly replaced by sulfides, unit 1, NDGS Well No. 2967, UND 2786. 9. Small, complete conch showing camarae and living chamber, lower shale member, NDGS Well No. 5088, UND 2785.
- 8 Indeterminate coiled cephalopod. Portion of one whorl; a small valve of Cyzicus (Lioestheria) sp. is pressed upon it, lower shale member, NDGS Well No. 2383, UND 2787.
- 10-13, 18 Cyzicus (Lioestheria) sp. 10. Valves from near the base of the lower shale member, NDGS Well No. 5088, UND 2793. 11. An unusually large right valve from near the base of the lower shale member, NDGS Well No. 5088, UND 2791. 12. The largest complete left valve found, near the base of the lower shale member, NDGS Well No. 2967, UND 2792. 13. Two nearly-articulated valves showing part of the interior of the left valve and most of the exterior of the right valve, X3, upper shale member, NDGS Well No. 607, UND 2794. 18. Conchostracan bed from near the top of the lower shale member, NDGS Well No. 2967, UND 2795.
- 14 Brachymetopus (Brachymetopus) sp. Minute pygidium. The border and pleural spines of the specimen are not visible, X20, unit 3, NDGS Well No. 8069, UND 2790.
- 15 Indeterminate eumalacostracan. Right, posterolateral part of a crushed and carbonized shrimp-like organism, X1.5, lower shale member, NDGS Well No. 5088, UND 2797.
- 16, 19 Foerstia sp. 16. Small, bifurcating thallus, X5.5, lower shale member, NDGS Well No. 4340, UND 2799. 19. Ovate to bi-

lobed thalli, lower shale member, NDGS Well No. 4340, UND 4344.

- 17 Crossopterygian (?) fish scale. Lower shale member, NDGS Well 607, UND 2798.



PLATE 3



1



2



3



5



7



8



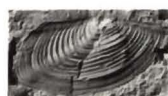
4



6



9



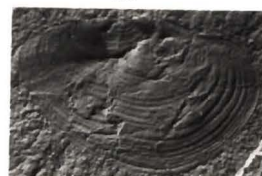
11



12



10



13



14



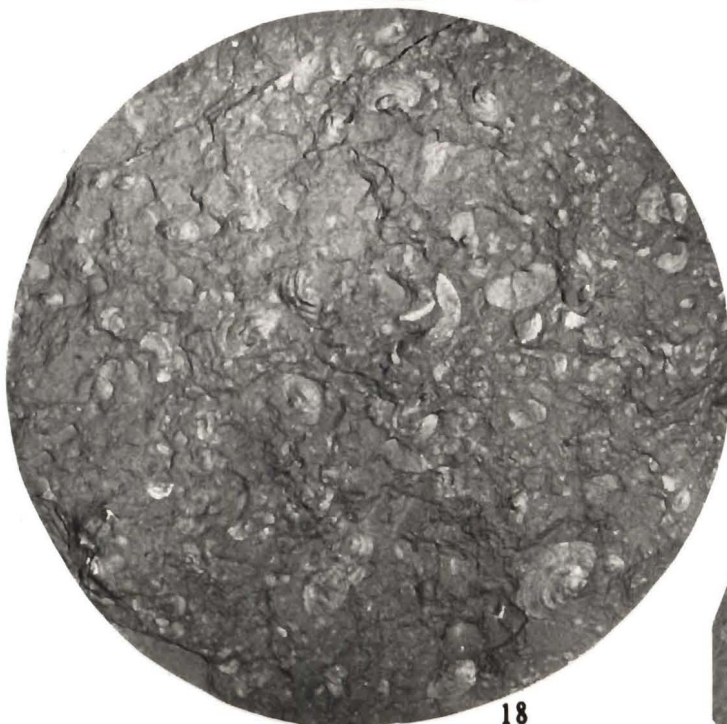
15



16



17



18



19

## EXPLANATION OF PLATE 4

All figures X1 unless otherwise indicated.

## Figure

- 1 Woody plant fragment. Upper shale member, NDGS Well No. 8177, UND 4347.
- 2 Planolites sp. Unit 1, NDGS Well No. 4340, UND 4350.
- 3 Ostracod-like valves. X4, lower shale member, NDGS Well No. 4340, UND 2796.
- 4 Chondrites sp. Unit 2, NDGS Well No. 2967, UND 4348.
- 5 Spirophyton-like trace fossil. X3.5, lower shale member, NDGS Well No. 2226, UND 4352.
- 6 Cosmoraphe sp. Unit 1, NDGS Well No. 5088, UND 4349.
- 7 Blade-like "leaves." Unit 2, NDGS Well No. 2967, UND 4345.
- 8 Scalaropoda missouriensis Weller. Unit 1, NDGS Well No. 5088, UND 4351.



PLATE 4



1



2



3



4



5



6



7



8

## APPENDICES

## APPENDIX 1



## APPENDIX

## NAME AND LOCATION OF CORES USED IN THIS STUDY

Well numbers in the far left column are those of the North Dakota Geological Survey and are listed in numerical order. Locations are based on the standard Land Office Grid System. In describing the location, Q/Q stands for first and second quarters of the section; S, T, and R stand for section, township, and range, respectively; C in the Q/Q column stands for center of quarter section. All townships in North Dakota are north and all ranges are west of the principal baseline and meridian.

NAME AND LOCATION OF CORES USED IN THIS STUDY

| <u>Well<br/>No.</u> | <u>Operator</u>              | <u>Well Name</u>                   | <u>Q/Q</u> | <u>S-T-R</u> | <u>County</u> |
|---------------------|------------------------------|------------------------------------|------------|--------------|---------------|
| 105                 | Stanolind Oil and Gas Co.    | Walter and Ingerberg Waswick No. 1 | SW/NE      | 2-153-85     | Ward          |
| 207                 | Continental Oil Co.          | Leuth No. 1                        | SE/SE      | 27-146-73    | Wells         |
| 413                 | Carter Oil Co.               | Edward Lockwood Jr. No.            | SE/SW      | 5-147-93     | Dunn          |
| 527                 | California Oil Co.           | Rough Creek Unit No. 1             | NW/NE      | 13-148-98    | McKenzie      |
| 607                 | Socony-Vacuum Oil Co.        | Angus Kennedy No. F 32-24-D        | SW/NE      | 24-149-93    | Dunn          |
| 793                 | Mobil Production Co.         | Solomon Bird Bear No. 1            | SE/NW      | 22-149-91    | Dunn          |
| 999                 | Texaco, Inc.                 | J. M. Donohue No.                  | SW/NE      | 23-154-100   | Williams      |
| 1202                | Amerada Petroleum Co.        | Jens Strand No.                    | SW/NW      | 6-152-94     | McKenzie      |
| 254                 | Northern Pump Co.            | Gilbert T. Rhode No.               | SW/SE      | 17-152-94    | McKenzie      |
| 343                 | Pan American Petroleum Corp. | Helen G. Price No. 3               | NW/SW      | 7-152-94     | McKenzie      |
| 1405                | Gofor Oil, Inc.              | Catherine E. Peck No. 2            | NW/NE      | 27-150-96    | McKenzie      |
| 1606                | Amerada Petroleum Corp.      | H. H. Shalvik Tract , No.          | NE/SW      | 35-150-97    | McKenzie      |
| 1679                | Amerada Petroleum Corp.      | C. C. Mogen Tract , No.            | SW/SE      | 10-153-96    | McKenzie      |
| 748                 | Amerada Petroleum Corp.      | Reed-Norby Unit No.                | NW/NE      | 6-152-94     | McKenzie      |
| 1858                | Amerada Petroleum Corp.      | Minnie Kummer Tract No.            | NW/NE      | 25-150-96    | McKenzie      |

|      | <u>Operator</u>              | <u>Well Name</u>                  | <u>Q/Q</u> | <u>S-T-R</u> | <u>County</u> |
|------|------------------------------|-----------------------------------|------------|--------------|---------------|
| 1886 | Amerada Petroleum Corp.      | John Dinwoodie No.                | NW/SE      | 3-153-94     | McKenzie      |
| 2226 | Amerada Petroleum Corp.      | USA Thomas No.                    | SW/NW      | 18-153-94    | McKenzie      |
| 2383 | Gul Of Corp.                 | Lawrence Bird's Bi No             | NW/NE      | 30-150-94    | McKenzie      |
| 2602 | Texaco, Inc                  | Garland No. 5                     | SW/NE      | 6-153-95     | McKenzie      |
| 2618 | Pan American Petroleum Corp. | Jacob Huber No.                   | SW/SE      | 5-145-91     | Dunn          |
| 2820 | Texaco, Inc.                 | F. D. Keough No.                  | NW/SW      | 5-151-95     | McKenzie      |
| 2828 | Texaco, Inc                  | Hovde No.                         | NW/NW      | 5-154-98     | Williams      |
| 2967 | Texaco, Inc                  | A. S. Wianess No. 2               | NW/SE      | -152-96      | McKenzie      |
| 3007 | Dallia Petroleum Corp        | Hamlet Unit No. 2                 | C/NE       | 30-159-95    | Williams      |
| 3167 | Texaco, Inc                  | W. Quale No.                      | SE/SW      | 31-153-95    | McKenzie      |
| 3363 | Texaco, inc.                 | Clarence Pederson (NCT-1) No.     | NW/SE      | 19-157-96    | Williams      |
| 4    | Texaco, inc                  | ort Berthold Allottees 437 No. -A | SE/NW      | 4-150-93     | Mountrail     |
| 4264 | Texaco, inc                  | Devonian Unit No. 5, Wel No.      | NE/NW      | 3-153-95     | McKenzie      |
| 4297 | Pan American Petroleum Corp. | B. Hove No.                       | SW/NE      | 2-154-95     | Williams      |
| 4340 | Pan American Petroleum Corp  | ifford Marmon No.                 | SW/SW      | 2-154-95     | Williams      |
| 4508 | Northern Pump Co.            | ouis Peterson No.                 | NE/NE      | 7-161-90     | Burke         |

| <u>Well<br/>No.</u> | <u>Operator</u>             | <u>Well Name</u>           | <u>Q/Q</u> | <u>S-T-R</u> | <u>County</u> |
|---------------------|-----------------------------|----------------------------|------------|--------------|---------------|
| 4958                | John B Hawley Jr. Trust No. | Florence M. Ingerson No. 2 | SW/NE      | 2-161-91     | Burke         |
| 5088                | Shell Oil Co.               | Shell-Texas No. 21-35      | NE/NW      | 35-156-93    | Mountrail     |
| 7579                | Shell Oil                   | USA No. 42-24A             | SE/NE      | 24-145-104   | McKenzie      |
| 785                 | Brooks Exploration, Inc     | Rogstad No.                | NE/SE      | 11-155-91    | Mountrail     |
| 7887                | Tenneco Oil Co.             | Mee USA No. -17            | SW/NE      | 17-142-100   | Billings      |
| 8069                | Marathon Oil Co.            | Jensen No. 12-44           | SE/SE      | 2-154-90     | Mountrail     |
| 8177                | Marathon Oil Co.            | Dobrinski No. 18-44        | SE/SE      | 18-151-87    | Ward          |
| 8474                | Tenneco Oil Co.             | Graham USA No. -15         | NE/SW      | 5-144-102    | Billings      |
| 935                 | Supron Energy Corp.         | Federal No.                | NW/SE      | 6-144-101    | Billings      |

## APPENDIX 2

## APPENDIX 2

## CORE DESCRIPTION SHEETS

The core description sheets of Appendix 2 are designed primarily to show the stratigraphic occurrence of the fossils collected from the Bakken Formation. Thus, cores from which no fossils were collected (NDGS Well Nos. 793, 1202, 1254, 1343, 1606, 1748, 1858, 1886, 2602, 2820, 2828, 3007, 4113, and 7579) are not included here; these cores are generally unfossiliferous and most represent a few feet of the lower shale member. Some of the poorly preserved, poorly exposed, or other multiple, duplicate specimens (especially those on larger core fragments) that were collected and encoded were subsequently returned to their core boxes; this accounts for apparent gaps in the numbering sequence of the fossils.

The gamma ray log was chosen to show the well-log characteristics of each core; other well logs are used only for those cores in which the gamma ray log was unavailable. The depths used on the core description sheets are the log depths on the five-inch scale and are measured in feet below Kelly bushing, which is typically about 10 feet above ground level. The depths marked on the core boxes are noted on the core description sheets and, as can be seen, commonly do not agree exactly with the log depths; the core-box depths were adjusted to those of the well logs by comparing lithic changes noted in the cores with comparable changes occurring on the logs. The core depths shown on each description sheet are only of the Bakken Formation and do not include the few feet of the subjacent or superjacent rocks that may also be shown. The lithology column of the description sheets is filled only where core was

available; gaps in the core, exceeding three feet or at stratigraphic contacts, are indicated by an X. The top and bottom of the cored section have either a solid line to indicate the beginning or end of the core or, in formations adjacent to the Bakken, a dashed line, to indicate that the core may or may not continue beyond that depth.

The lithic descriptions do not include the "hardness" of the rocks because all of the rocks were found to be well indurated and "hard". The descriptions also do not note the presence of fractures in the cores; such fractures were fairly common in the black shale members, were commonly filled with calcite, and are currently being studied by Wayne B. Freisatz at the University of North Dakota in Grand Forks. The terms "lamination" and "bed" in the lithic descriptions of the middle member are used somewhat loosely; laminae are strata less than one inch thick and beds are strata generally less than a few inches thick.

Most of the abbreviations (or slight variations thereof) used for describing the rocks are found in a list of suggested abbreviations for lithic descriptions prepared by Mitchell and Maher (1957). They noted (p. 2104) that the words are generally abbreviated by eliminating the vowels or by using the first three or four letters of a word; they stated further, however, that, "So many exceptions to any one rule were found to be necessary that attempts to formulate a general rule were abandoned." Abbreviations used in the core description sheets that were not included in Mitchell and Maher's list are:

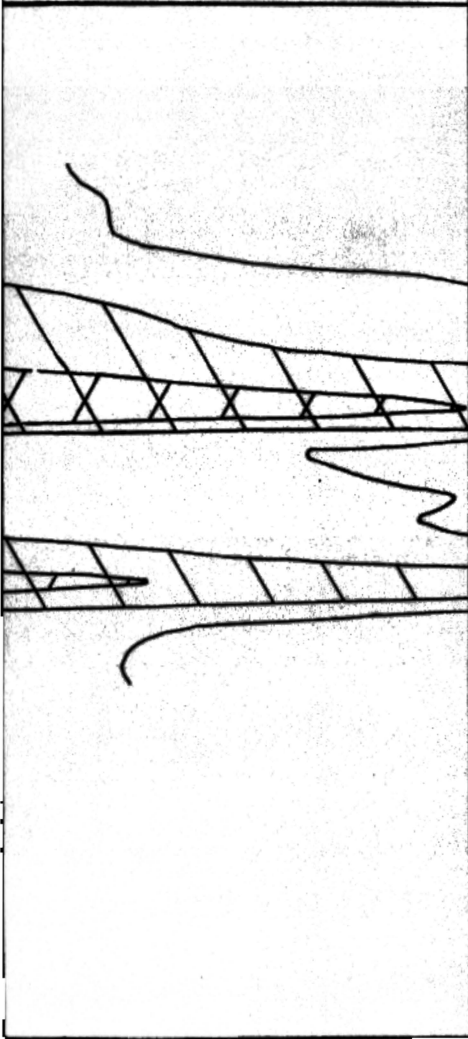
- aa -- as above
- bioturb -- bioturbated (bioturbation)
- Conch -- conchostracan
- Cono -- conodont
- cont -- continuous
- disc -- discontinuous
- ip. -- in part
- occ -- occasional


pc -- piece  
sm -- some  
unfos -- unfossiliferous

Many of the descriptive terms used here are modified with "very" or "slightly" by preceding the word with a "v" or a "sl"; colors are generally preceded by "lt", "m", or "dk" for light, medium, or dark, respectively. The term "Crin" is used loosely for any pelmatozoan fragment. Abbreviations for the stratigraphic units on the core description sheets are:

TF -- Three Forks Formation  
Lbs -- Lower black shale member of the Bakken Formation  
Mm1 -- Unit 1 of the middle member of the Bakken Formation  
Mm2 -- Unit 2 of the middle member of the Bakken Formation  
Mm3 -- Unit 3 of the middle member of the Bakken Formation  
Ubs -- Upper black shale member of the Bakken Formation  
L -- Lodgepole Formation

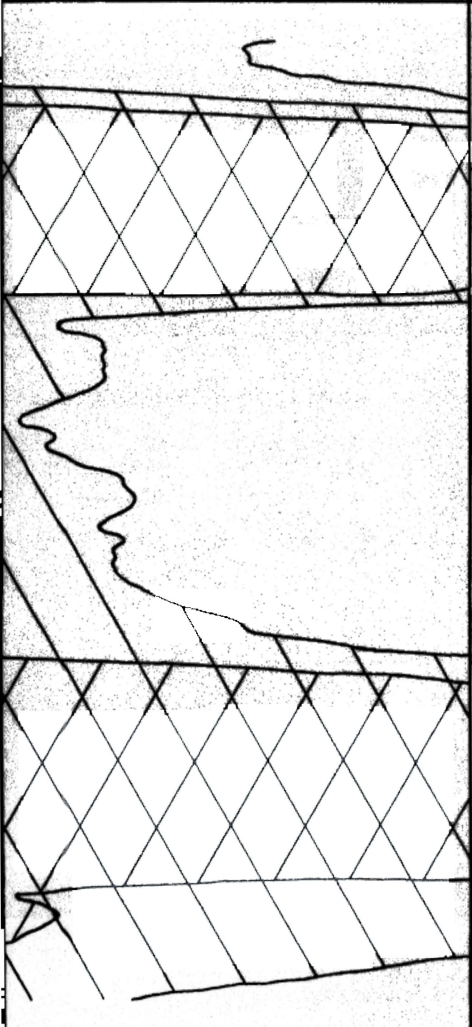


| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 105<br>CORE DEPTH: 7552-7564' SIZE: 3½" CONDITION: GOOD |
|--|------------------------|------|----------------|--------------------------|---|
|  | 7540-                  |      |                |                          |   |
|  |                        | L    |                |                          |   |
|  |                        | Ubs  |                |                          | SH dkgy-blk, carb, pyr, sil, fis  |
|  | 60-                    | Mm3  |                | 105.5-                   | SH aa   |
|  |                        | ?    |                | 105.1                    | SLTST ltgy, vfos (pred Brac), slcalc w/ sm wvy bdg                                      |
|  |                        | Mm2  |                |                          | SLTST aa, unfos, incr wvy, disc bdg; intbd SS, lt-                                      |
|  |                        | Mm1  |                |                          | gy, vfgr, vcalc, pyr  |
|  |                        | Lbs  |                |                          |   |
|  | 7580-                  | TF   |                |                          |   |

| SPONTANEOUS POTENTIAL LOG<br>→ 20 MILLIVOLTS                                       | LOG<br>DEPTH<br>(feet) | UNIT      | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 207<br>CORE DEPTH: 4195-4205'    SIZE: 3½"    CONDITION: GOOD |
|--|------------------------|-----------|----------------|--------------------------|---|
|  | 4160-                  |           |                |                          |   |
|  | 80-                    |           |                |                          |   |
|  | 4200-                  | L<br>Ubs? |                | 207.1                    | DOLO ltrdgy, fxln, suc<br>SH m-dkgy, sil, slsly, fis  |
|  |                        | TF?       |                |                          | SH aa, w/ Conulariid frag<br>SH aa, unfos   |
|  | 4240-                  |           |                |                          | DOLO ltrdgy, suc, vug   |



| RESISTIVITY (LL7) LOG<br>OHMS-M | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 413<br>CORE DEPTH: 10391-10469'; chips at 1' intervals |
|---------------------------------|------------------------|------|----------------|--------------------------|--|
| 10                              | 200                    |      |                |                          |  |
|                                 | 10380                  |      |                |                          |  |
|                                 |                        | L    |                |                          | LS lt-mgy, vfxln   |
|                                 |                        |      |                | 413.2                    | SH dkgy-blk, carb, slpyr, sil-slcalc, slsly, fis                                       |
|                                 |                        | Ubs  |                |                          | SH aa, decr dkgy, calc, slty   |
|                                 | 10400                  |      |                |                          | SH blk, carb, pyr, sil, fis  |
|                                 |                        |      |                | 413.1                    | SH aa  |
|                                 |                        | Mm3  |                |                          | SLTST ltgy, fos (Brac), calc, pyr  |
|                                 | 20                     |      |                |                          | SLTST aa, unfos, incr calc   |
|                                 |                        | Mm2  |                |                          | LS mgy, vf-micxln, slarg, slpyr  |
|                                 |                        |      |                |                          | SLTST mgy, slcalc-calc, vslpyr   |
|                                 | 40                     |      |                |                          | SLTST aa, w/ abnt Plant  |
|                                 |                        | Mm1  |                |                          | SLTST mgy, bioturb, slcalc-calc, slpyr   |
|                                 |                        |      |                |                          | SLTST aa, vcalc  |
|                                 |                        |      |                |                          | SH blk, vfos (Conch), sil, carb, pyr, fis  |
|                                 | 10460                  | Lbs  |                |                          | SH aa, unfos   |
|                                 |                        |      |                |                          | SH dkgy, sil, slsly, fis   |
|                                 |                        | TF   |                |                          | SH mgrngy, dolo  |

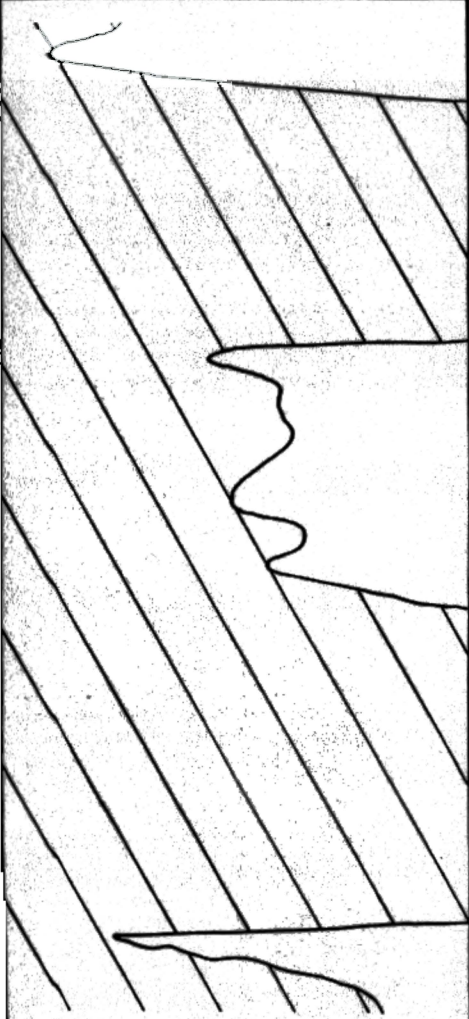
| GAMMA RAY LOG<br>—10 API UNITS   | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 527<br>CORE DEPTH: 11225-11295' SIZE: 2" CONDITION: POOR  |
|--|------------------------|------|----------------|--------------------------|---|
|  | 11200                  | L    |                |                          |   |
|  |                        | Ubs  |                |                          |   |
|  | 20                     | Mm3  |                |                          | SLTST m-dkgy, slfos (Brac), slcalc, slpyr   |
|  |                        | Mm2  |                | 527.2                    | SLTST aa, unfos, w/ wvy, disc bdg, sm xbdg<br>SLTST mgy, slcalc, arg, lam, intbdd w/ SS, ltgy, vfgr, calc<br>SLTST lt-mgy, slcalc, arg, w/ disc, wvy bdg, sm xbdg<br>SLTST aa, decr bdg |
|  | 40                     | Mm1  |                |                          | SLTST mgy, slfos (Brac), arg ip., bioturb, w/ sm disc bdg<br>SLTST aa, decr fos, bdg<br>LS ltgy, vf-fxln, vslty, arg, pyr<br>SLTST mgy, sm Brac, calc, arg ip., slpyr, slbioturb        |
|  | 60                     | Lbs  |                |                          | SH blk, sil, carb, pyr, fis<br><br>SH aa  |
|  | 11280                  |      |                | 527.1                    | SH dkgybrn-blk, slcalc, slcarb, slpyr, fis<br>SH aa, w/ tr Brac   |
|  |                        | TF   |                |                          | LS mgy, vf-fxln, slty<br>SS ltgy, vfgr, sbang, slty ip., grdg into SLTST  |
|  |                        |      |                |                          |   |
|  |                        |      |                |                          |   |



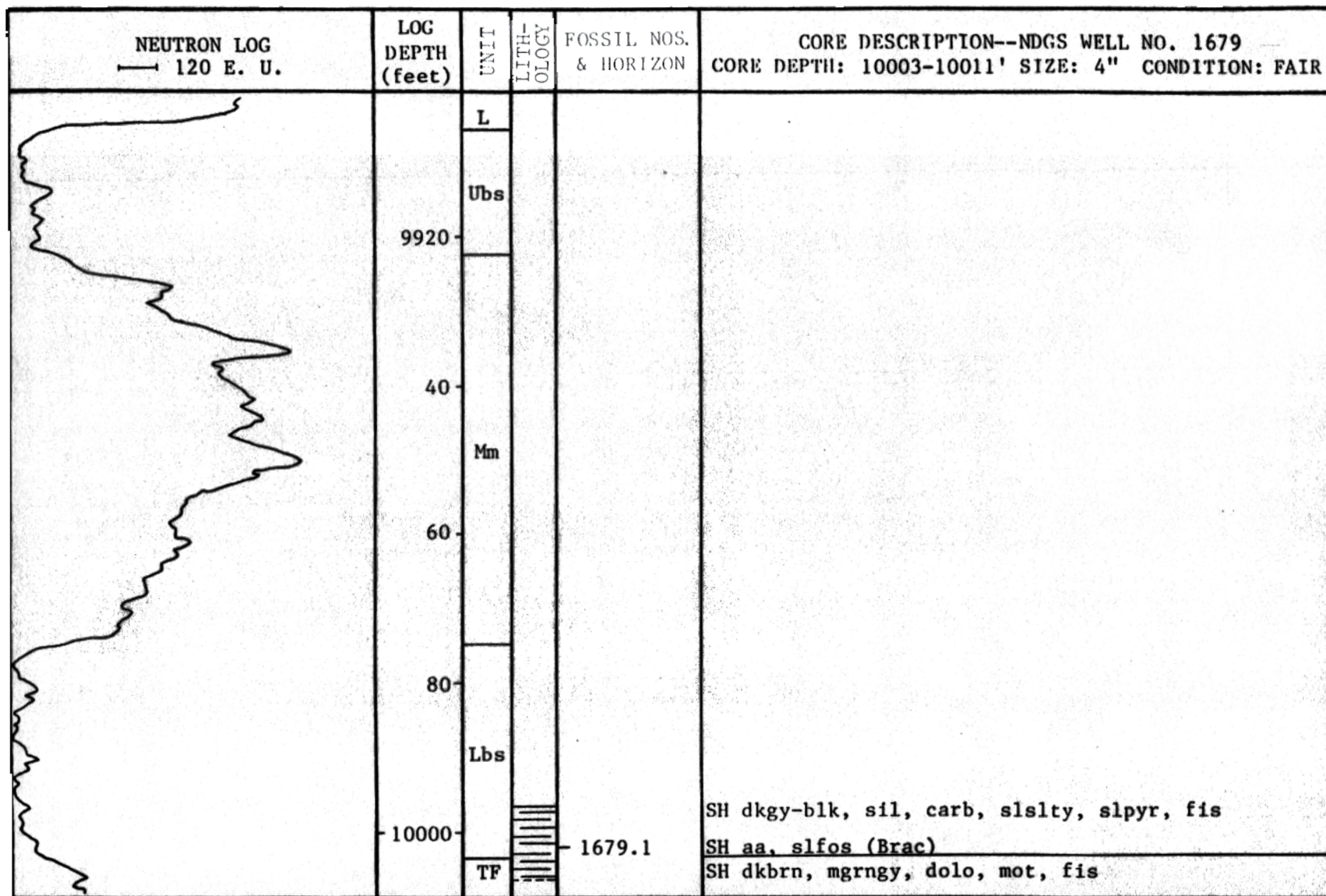
| GAMMA RAY LOG<br>—10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON    | CORE DESCRIPTION--NDGS WELL NO. 607<br>CORE DEPTH: 10508-10610' SIZE: 2½" CONDITION: GOOD |
|--------------------------------|------------------------|------|----------------|-----------------------------|---|
|                                |                        | L    |                |                             | LS mgy, vf-micxln, slfos (Crin)   |
|                                |                        |      |                |                             | SH dkgy-blk, sil, carb, pyr, fis  |
|                                | 10520                  | Ubs  |                | 607.15<br>607.14-<br>607.12 | SH aa, w/ sm Conch, Fish frag   |
|                                |                        | Mm3  |                | 607.11.6-<br>607.11.2       | SH dkgy-blk, sil, carb, pyr, fis, w/ abnt Cono  |
|                                |                        |      |                |                             | SLTST m-dkgy, slfos (Brac), sil-calc, arg ip.   |
|                                |                        |      |                |                             | SLTST mgy, calc-vcalc, intlaml w/ SH, dkgy, sil   |
|                                | 40                     | Mm2  |                |                             | SS lt-mgy, f-cgr, sbang, vcalc, sm xbdg   |
|                                |                        |      |                |                             | LS lt-mgy, m-cxln, slty-vsndy   |
|                                |                        |      |                |                             | SLTST mgy, calc, arg, even bdg, intlaml w/ SH, aa   |
|                                |                        |      |                | 607.11<br>607.10            | SLTST lam, aa, w/ abnt Plant  |
|                                |                        |      |                |                             | SLTST mgy, calc, arg, bioturb ip., sm even bdg  |
|                                | 60                     | Mm1  |                | 607.9.4<br>607.9.2          | SLTST mgy, tr Brac, calc, slarg, bioturb  |
|                                |                        |      |                | 607.9                       | SLTST slfos, bioturb, aa  |
|                                |                        |      |                |                             | SLTST aa, incr fos, slpyr   |
|                                |                        |      |                | 607.8.8-<br>607.8.4         | SLTST mgy, fos (Brac), calc, arg ip., slpyr   |
|                                | 80                     |      |                | 607.8                       | SH dkgy-blk, sil, carb, asph ip., pyr, w/ sm Fish frag                                    |
|                                |                        |      |                | 607.7                       | SH aa   |
|                                |                        | Lbs  |                | 607.6-<br>607.5.2           | LS mgy, fxln, arg, pyr  |
|                                |                        |      |                |                             | SH aa, w/ Fish Scs  |
|                                |                        |      |                | 607.5                       | SH dkgy, slfos (Brac, Conch), sil, carb, pyr, fis   |
|                                | 10600                  |      |                | 607.4-<br>607.1             | LS ltgy, mxln, slarg  |
|                                |                        |      |                |                             | SH aa   |
|                                |                        | TF   |                |                             | SH lt-mgygrn, dolo  |




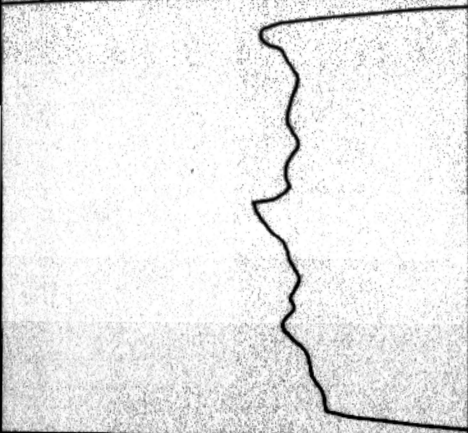
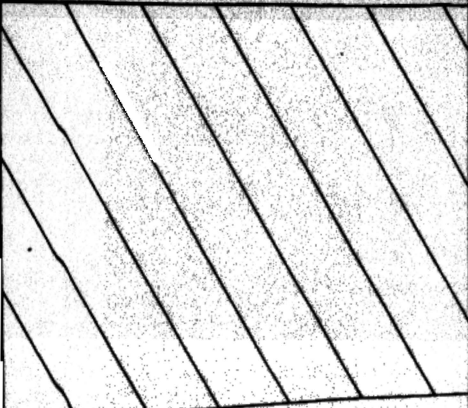
| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT              | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 999<br>CORE DEPTH: 10984-11026' SIZE: 2½" CONDITION: POOR |
|---------------------------------|------------------------|-------------------|----------------|--------------------------|---|
|                                 | 10920                  |                   |                |                          |   |
|                                 |                        | L                 |                |                          |   |
|                                 | 40                     | Ubs               |                |                          |   |
|                                 | 60                     | Mm<br>3<br>&<br>2 |                |                          |   |
|                                 |                        | ?                 |                |                          |   |
|                                 | 80                     | Mml               |                | 999.2                    | SLTST lt-mgy, slfos (Brac), slcalc, bioturb   |
|                                 | 11000                  | Lbs               |                |                          | SLTST aa, incr Brac   |
|                                 |                        |                   |                |                          | SH blk, sil, slcarb-carb, pyr, fis  |
|                                 | 11020                  | TF                |                |                          | SH aa<br>SH lt-mgrngy, dolo   |

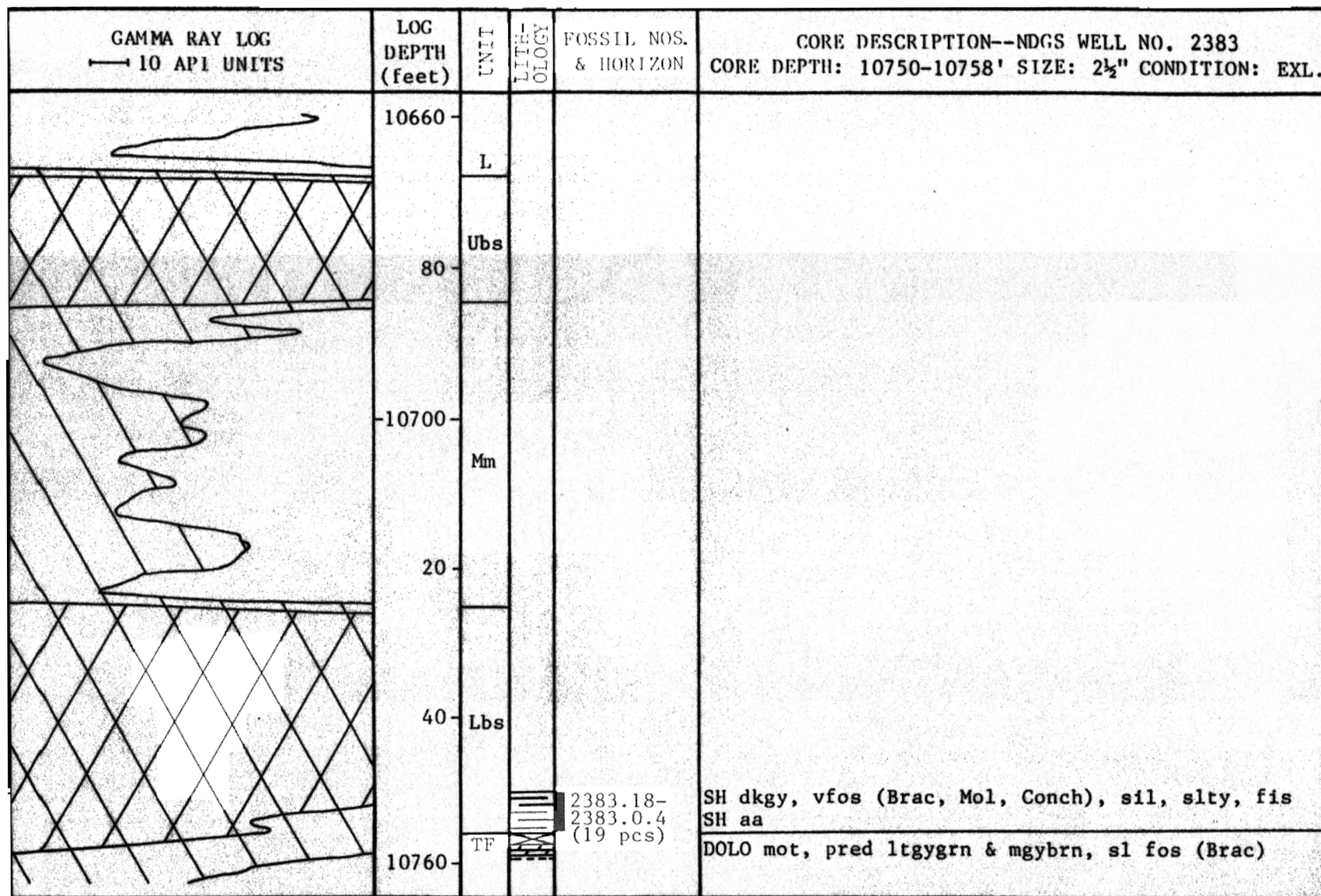
| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 1405<br>CORE DEPTH: 10759-10820' SIZE: 4" CONDITION: FAIR  |
|--|------------------------|------|----------------|--------------------------|--|
|  | 10740                  | L    |                |                          |  |
|  |                        | Ubs  |                |                          |  |
|  | 60                     |      |                |                          |  |
|  |                        | Mm3  |                |                          | SLTST m-dkgy, slfos (Brac), sil-slcalc, slpyr, occ<br>intbd w/ SS, ltgy, vf-fgr, calc  |
|  |                        | Mm2  |                |                          | SLTST aa, unfos, intbd w/ SS, aa<br>SLTST lt-mgy, sil-slcalc, w/ wvy, disc bdg, xbdd,<br>intbdd w/ SS, aa, & SH, dkgy, sil<br>SLTST aa, decr xbdg  |
|  | 80                     |      |                |                          | SLTST aa w/ tr Plant   |
|  |                        | Mm1  |                | 1405.4<br>1405.3         | SLTST lt-mgy, slfos (Brac), sil-slcalc, arg, bio-<br>turb, occ intbd w/ SS, ltgy, vf-fgr, calc<br>SLTST mgy, slfos, bioturb, aa, w/ abnt SS bds, aa<br>SLTST aa, incr fos, occ intbd w/ SS, aa |
|  | 10800                  |      |                | 1405.2                   | SH blk, sil, carb, pyr, fis  |
|  |                        | Lbs  |                |                          | SH aa, vasph ip<br>LS dkgy, f-mxln, arg, pyr, suc<br>SH aa   |
|  | 10820                  |      |                |                          | SH aa  |
|  |                        | TF   |                |                          | SH vgted, pred mgygrn, dolo  |



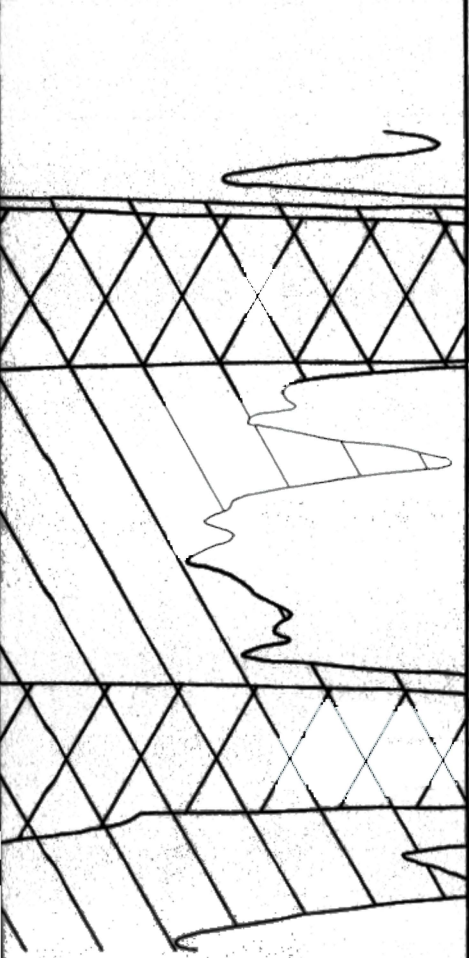




| GAMMA RAY LOG<br>—10 API UNITS   | LOG<br>DEPTH<br>(feet) | UNIT        | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 2226<br>CORE DEPTH: 10578-10590' SIZE: 2½" CONDITION: FAIR                      |
|--|------------------------|-------------|----------------|--------------------------|---|
|   | 10500                  | Ubs<br>(pt) |                |                          | Top of Bakken @ 10485'  |
|  | 20                     |             |                |                          |   |
|   | 40                     | Mm          |                |                          |   |
|  | 60                     |             |                |                          |   |
|  | 80                     | Lbs         |                |                          |   |
|  | 10600                  | TF          |                | 2226.1                   | SH dkgy-blk, sil, carb, asph ip., pyr, fis, w/<br>Trace Fossil<br>SH aa, unfos, decr dkgy<br>SH mgy-mgrngy, sil |



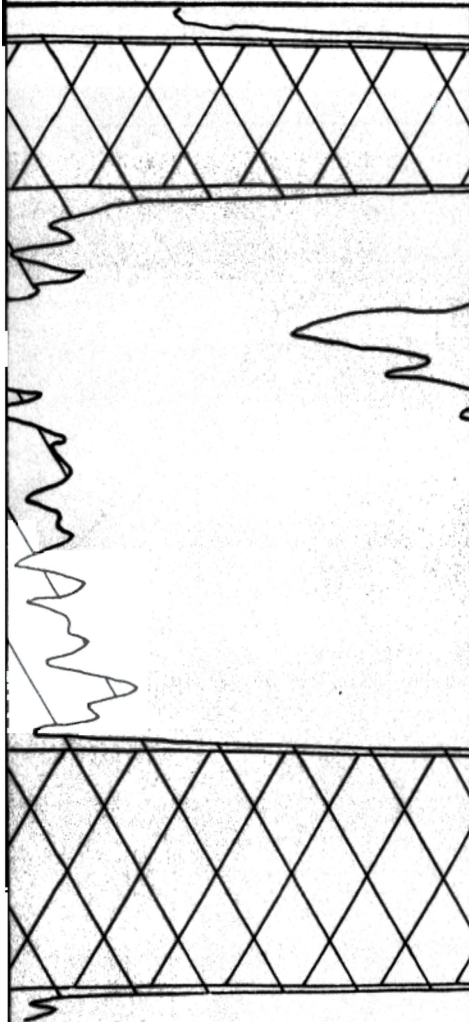
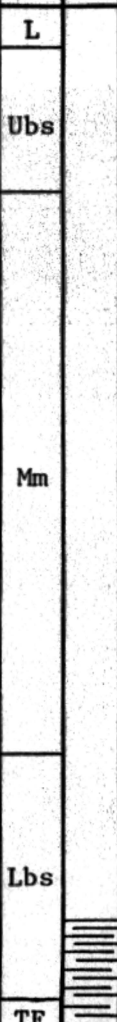


| GAMMA RAY LOG<br>→ 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 2618<br>CORE DEPTH: 9794-9838' SIZE: 2½" CONDITION: FAIR   |
|--|------------------------|------|----------------|--------------------------|--|
|  | 9760                   |      |                |                          |  |
|  |                        | L    |                |                          |  |
|  | 80                     | Ubs  |                |                          |  |
|  |                        | Mm3  |                | 2618.4-<br>2618.2        | SLTST lt-mgy, sm Brac, sil-calc, varg ip., vsndy<br>ip., intbdd w/ LS, ltgy, fos (Brac), vfxln, slty   |
|  | 9800                   | Mm2  |                |                          | SLTST aa, unfos, w/ wvy, disc bdg, sm xbdg, intbdd<br>w/ SH, dkgy, sil, & SS, ltgy, calc, fgr<br>LS ltgy, vf-fxln, slty<br>SLTST mgy, sil-slcalc, w/ wvy bdg, intlamm w/ SS,<br>aa, & LS, aa<br>SLTST aa, w/ wvy, disc bdg |
|  | 20                     | Mm1  |                | 2618.1                   | SLTST mgy, tr Brac, sil-slcalc, bioturb ip., sm wvy<br>bdg, intbdd w/ LS, ltgy, slfos, vf-fxln, slty<br>SLTST lt-mgy, sl fos (Brac), slcalc, arg ip., bio-<br>turb, w/ sm disc bdg   |
|  |                        | Lbs  |                |                          | SLTST aa, slpyr, incr fos<br>SH blk, sil, carb, slpyr, fis<br>SH aa, incr pyr<br>SH blk, sil, carb, pyr, fis   |
|  | 9840                   | TF   |                |                          | SH ltgy-ltblgy, dolo   |

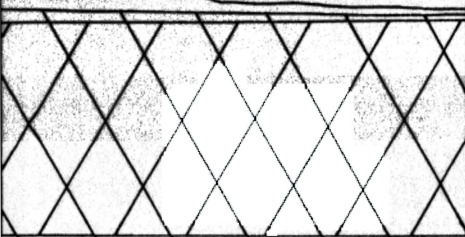
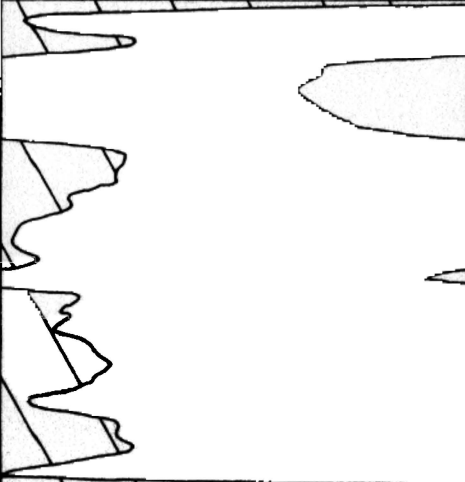
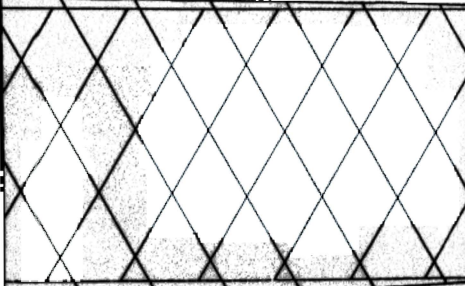
| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON                            | CORE DESCRIPTION--NDGS WELL NO. 2967<br>CORE DEPTH: 10238-10303' SIZE: 4" CONDITION: GOOD   |
|---------------------------------|------------------------|------|----------------|---|---|
|                                 | 10220                  | L    |                |   |   |
|                                 |                        | Ubs  |                |   |   |
|                                 | 40                     |      |                |   |   |
|                                 |                        | Mm3  |                | 2967.17-<br>2967.15                                 | SLTST lt-mgy, sm Brac, slcalc, arg ip., w/ even bdg<br>SLTST aa, decr fos, incr even, cont bdg  |
|                                 | 60                     | Mm2  |                | 2967.14   | SLTST mgy, slcalc, w/ bdg, aa<br>SS mgy, vf-mgr, vcalc, rnd-sbrnd, even-wvy lam<br>SLTST m-dkgy, slcalc, even-wvy bdd, intbdd w/ SS,<br>ltgy, fgr, calc, & SH, dkgy, sil<br>SLTST aa, w/ Trace Fossil |
|                                 |                        |      |                | 2967.13.5<br>2967.13<br>2967.12                     | SLTST bdd, aa, w/ abnt Plant  |
|                                 | 80                     | Mm1  |                | 2967.11.6-<br>2967.8<br>2967.7<br>2967.6-<br>2967.4 | SLTST lt-mgy, slfos (Brac), slcalc-calc, bioturb<br>ip., decr bdg<br>SLTST bioturb, aa, incr fos<br>SLTST mgy, slfos, calc, arg, slpyr, sm bioturb  |
|                                 |                        |      |                | 2967.2-<br>2967.1                                   | SLTST aa, incr fos, decr bioturb  |
|                                 | 10300                  | Lbs  |                |   | SH blk, vfos (Conch), sil, carb, pyr, fis<br>SH aa, unfos<br><br>SH blk, sil, vcarb, asph, pyr, fis   |
|                                 |                        | TF   |                |   | SH aa, w/ tr Conch<br>SH blk, sil, carb, pyr, fis<br>SH mgrn, sil   |
|                                 | 10320                  |      |                |   |   |

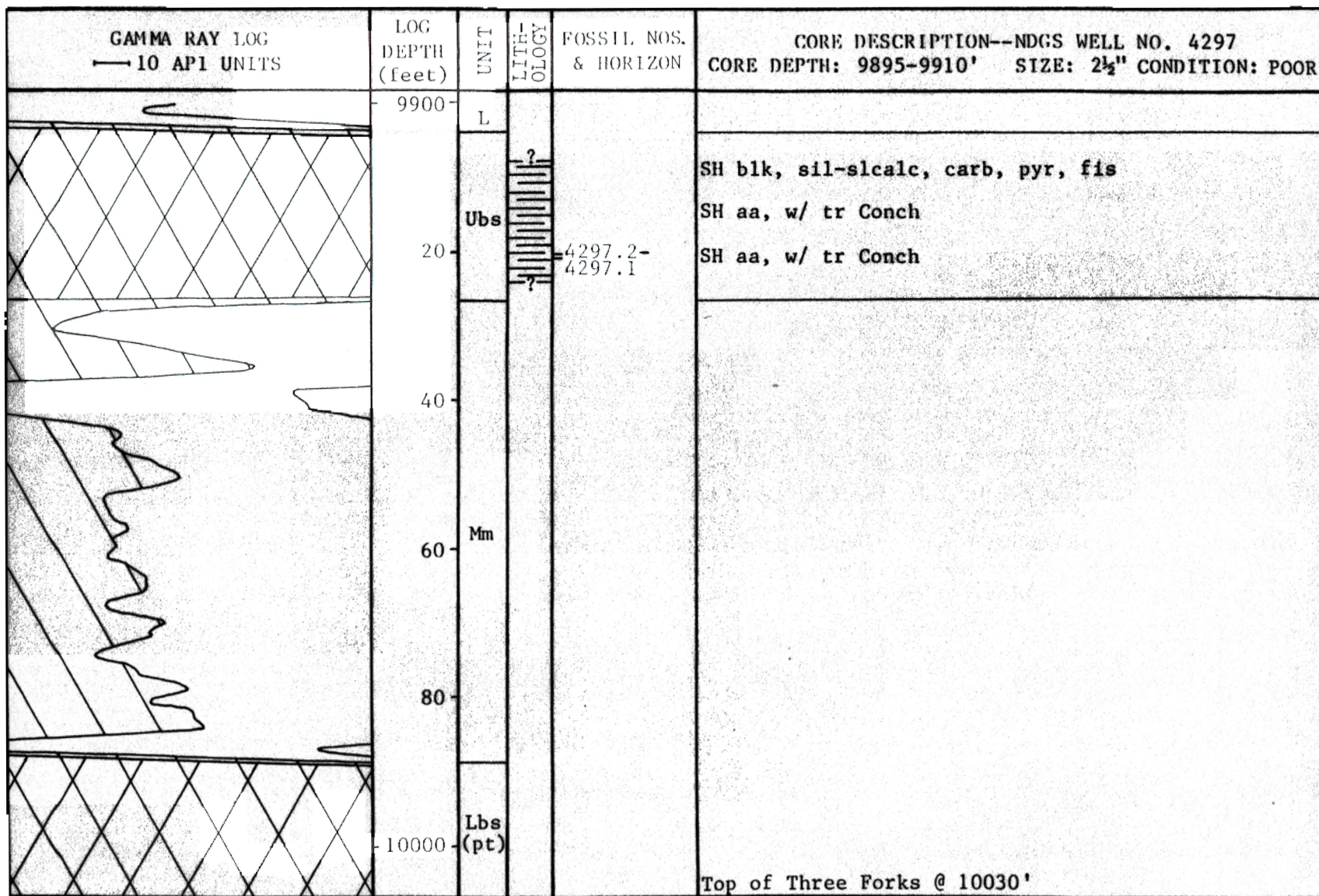


| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 3167<br>CORE DEPTH: 10198-10267' SIZE: 2½" CONDITION: GOOD  |
|---------------------------------|------------------------|------|----------------|--------------------------|---|
|                                 | 10180                  | L    |                |                          |   |
|                                 |                        | Ubs  |                |                          |   |
|                                 | 10200                  | Mm3  |                | 3167.4<br>3167.3         | SLTST lt-mgy, sm Brac, slcalc, sndy ip., wvy bdg<br>SLTST lt-mgy, slcalc, even-wvy bdd, intlamm w/ SH,<br>dkgy, sil<br>SS ltgy, vf-fgr, vcalc, sbang-sbrnd, slsly, grdg<br>into LS, m-dkgy, m-cxln, ool, vsndy ip.<br>SLTST m-dkgy, slcalc, lam, w/ abnt even bds of SS,<br>vf-fgr, calc, & SH, dkgy, sil |
|                                 | 20                     | Mm2  |                |                          | SLTST lam, aa, w/ abnt Plant  |
|                                 |                        |      |                | 3167.2.8-<br>3167.2      | SLTST m-dkgy, slfos (Brac), slcalc, slty ip., bio-<br>turb, sm disc bdg   |
|                                 | 40                     | Mm1  |                |                          | SLTST m-dkgy, sm Brac, calc, arg, slsndy  |
|                                 |                        |      |                | 3167.1.1<br>3167.1       | SLTST slfos (Brac), aa, incr dkgy, arg, decr calc<br>SH blk, vfos (Conch), sil, carb, pyr, fis<br>SH aa, unfos  |
|                                 | 10260                  | Lbs  |                |                          | SH aa   |
|                                 |                        |      |                |                          | SH dkgy-blk, sil, carb, pyr, fis  |
|                                 |                        | TF   |                |                          | SH mgygrn, sil  |

| GAMMA RAY LOG<br>→ 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY   | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 3363<br>CORE DEPTH: 10213-10223' SIZE: 3½" CONDITION: GOOD                         |  |  |  |
|--|------------------------|------|--|--------------------------|--|--|--|--|
|  | 10140-                 | L    |  | 3363.5-<br>3363.2        | SH dkgy-blk, slfos (Ost), sil, carb, pyr, fis<br>SH aa, w/ tr Cono<br>SH blk, sil, carb, pyr, fis<br>SH mgrn, dolo |  |  |  |
|  |                        | Ubs  |  |                          |  |  |  |  |
|  | 60-                    | Mm   |  |                          |  |  |  |  |
|  | 80-                    |      |  |                          |  |  |  |  |
|  | 10200-                 | Lbs  |  |                          |  |  |  |  |
| 10220-   | TF                     |      |  |                          |  |  |  |  |




| GAMMA RAY LOG<br>— 10 API UNITS   | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 4264<br>CORE DEPTH: 10023-10033' SIZE: 4" CONDITION: FAIR |
|---|------------------------|------|----------------|--------------------------|---|
|    | 9940                   | Ubs  |                |                          |   |
|   | 60                     |      |                |                          |   |
|   | 80                     | Mm   |                |                          |   |
|   | 10000                  |      |                |                          |   |
|  | 10020                  | Lbs  |                |                          |   |
|   |                        |      |                | 4264.1                   | SH blk, vslfos (Ost), sil, carb, pyr, fis   |
|   |                        |      |                |                          | SH dkgy-blk, tr Brac, sil, carb, slsly, pyr, fis  |
|   |                        | TF   |                |                          | SH mgrn, dolo   |

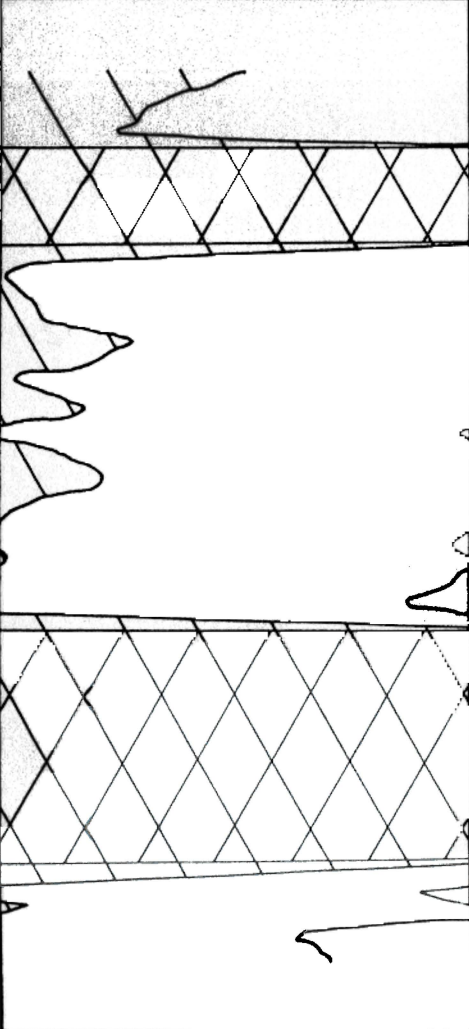




| GAMMA RAY LOG<br>—10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT        | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON                           | CORE DESCRIPTION--NDGS WELL NO. 4340<br>CORE DEPTH: 9886-10015' SIZE: 3½" CONDITION: FAIR                               |
|--------------------------------|------------------------|-------------|----------------|--|---|
|                                | 80-                    |             |                |  |   |
|                                |                        | L           |                |  |   |
|                                | 9900-                  |             |                |  | SH blk, sil-silcalc, carb, pyr, fis<br>SH aa, decr calc<br>SH blk, sil, carb, pyr fis                                   |
|                                |                        | Ubs         |                | 4340.17<br>4340.16                                 | SH aa   |
|                                | 20-                    | Mm3         |                | 4340.15-<br>4340.13                                | SLTST lt-mgy, fos (Brac), sil-silcalc, slpyr, lam,<br>sm xbdg   |
|                                |                        |             |                |  | SLTST lt-mgy, silcalc, pred even bdd, sm xbdd<br>LS lt-mgy, mic-vfxln, vsndy, intbdd w/ SS, ltgy,<br>vf-fgr, vcalc      |
|                                | 40-                    | Mm2         |                |  | LS aa, w/ abnt SS bds, aa<br>SLTST mgy, calc-vcalc, w/ wvy, disc bdg, sm xbdd<br>SLTST mgy, calc, w/ bdg, aa, decr xbdg |
|                                |                        |             |                |  | SLTST mgy, calc, w/ even-slwvy bdg  |
|                                | 60-                    |             |                | 4340.12<br>4340.11                                 | SLTST mgy, slfos (Brac), sl bioturb, silcalc-calc,<br>w/ sm wvy, disc bdg<br>SLTST aa, incr bioturb, decr bdg           |
|                                |                        | Mm1         |                | 4340.10<br>4340.8<br>4340.7<br>4340.6.4-<br>4340.5 | SLTST m-dkgy, slfos (Brac), sm bioturb, calc-<br>vcalc, slarg, w/ Trace Fossil<br>SLTST aa, incr Brac                   |
|                                | 9980-                  | Lbs<br>(pt) |                |  | Lower black shale member on next page   |



| GAMMA RAY LOG<br>→ 10 API UNITS   | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON   | CORE DESCRIPTION--NDGS WELL NO. 4340<br>CONTINUED FROM LAST PAGE |
|---|------------------------|------|----------------|----------------------------|--|
|  | 9980                   | Mml  |                |                            | Upper two members of Bakken on preceding page                    |
|   |                        |      |                |                            | SH dkgy-blk, fos (Conch), sil, carb, slsly, pyr,<br>fis          |
|   |                        |      |                |                            | SH aa, unfos, decr slty  |
|   | 10000                  | Lbs  |                | 4340.4<br>4340.3<br>4340.2 | SH dkgy-blk, slfos (Ost), sil, carb, slsly ip.,<br>pyr, fis      |
|   |                        |      |                |                            | SH aa, w/ occ Ost, asph ip.                                      |
|   |                        |      |                | 4340.1-<br>4340.0.2        | SH aa, w/ <u>Foerstia</u>  |
|   |                        |      |                |                            | LS mgy, fxln, pyr, suc   |
|   | 20                     |      |                |                            | SH dkgy, sil, slcarb, slsly-sly, slpyr, fis                      |
|   |                        | TF   |                |                            | SH aa  |
|   |                        |      |                |                            | SH m-dkgrngy, dolo   |
|   | 10040                  |      |                |                            |  |

| GAMMA RAY LOG<br>→ 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 4508<br>CORE DEPTH: 7503-7552' SIZE: 4" CONDITION: GOOD |
|--|------------------------|------|----------------|--------------------------|---|
|  | 7480-                  |      |                |                          |   |
|  |                        | L    |                |                          |   |
|  |                        | Ubs  |                |                          |   |
|  | 7500-                  |      |                |                          |   |
|  |                        | Mm3  |                |                          | SLTST lt-mgy, slfos ip. (Brac), sil-slcalc, slpyr, arg                                  |
|  |                        |      |                |                          | SLTST slfos. aa. w/ abnt lams of SH, dkgy, sil  |
|  |                        | Mm2  |                |                          | SLTST mgy, sil-calc, pyr ip., even-wvy bdd, sm x-bdg, intlams w/ SH, dkgy, sil          |
|  | 20-                    |      |                |                          | SLTST aa, decr xbdg   |
|  |                        |      |                |                          | SLTST mgy, slcalc, w/ even-wvy, disc bdg  |
|  |                        |      |                |                          | SLTST mgy, sil-slcalc, sm wvy, disc bdg, pred bioturb                                   |
|  |                        | Mm1  |                |                          | SLTST mgy-mgrngy, calc, arg ip., slpyr, sm bioturb                                      |
|  |                        |      |                |                          | SLTST aa, slfos (Brac), decr bioturb  |
|  | 40-                    |      |                | -4508.1                  | SLTST mgy-mgygrn, fos (Brac), slcalc, sm bioturb  |
|  |                        |      |                |                          | SLTST fos. aa   |
|  |                        |      |                |                          | SH blk, sil, carb, pyr, fis   |
|  |                        | Lbs  |                |                          | SH aa   |
|  | 60-                    |      |                |                          |   |
|  |                        | TF   |                |                          |   |
|  | 7580-                  |      |                |                          |   |

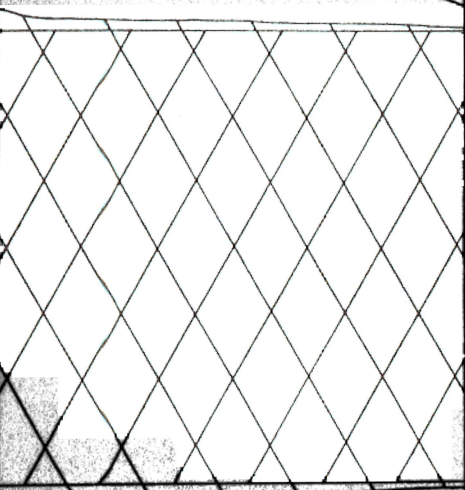

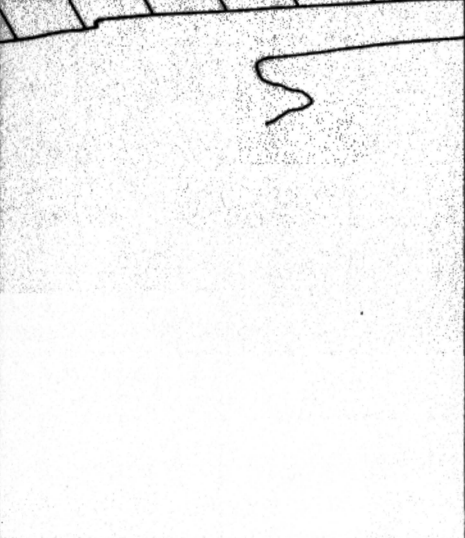


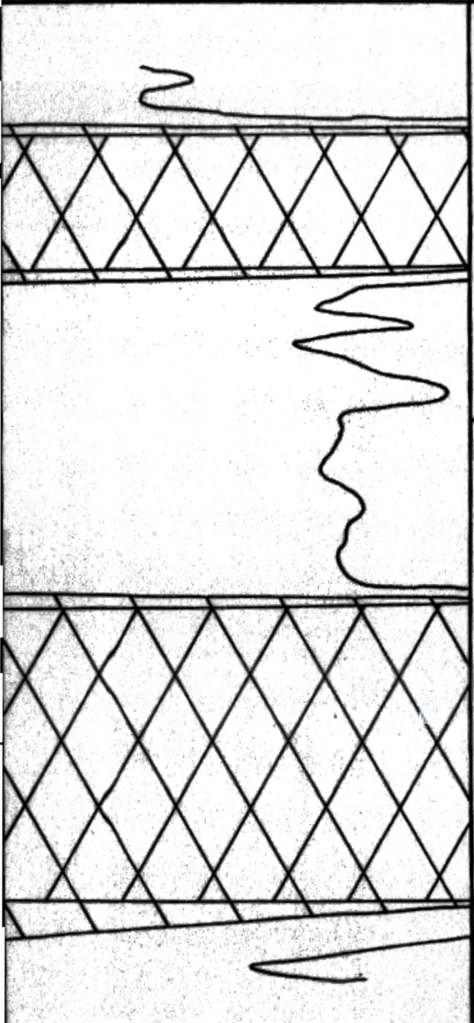
| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON       | CORE DESCRIPTION--NDGS WELL NO. 4958<br>CORE DEPTH: 7577-7624' SIZE: 3½" CONDITION: EXL.  |
|---------------------------------|------------------------|------|----------------|--------------------------------|---|
|                                 | 7560                   | L    |                |                                |   |
|                                 |                        | Ubs  |                |                                |   |
|                                 | 80                     | Mm3  |                | 4958.14-<br>4958.6<br>(11 pcs) | SH dkgy-blk, sil, carb, pyr, fis, abnt Cono<br>SLTST lt-mgy, vfos (Brac), sil-slcalc, arg, sndy ip<br>SLTST aa, decr fos, intlaml w/ SH dkgy, sil |
|                                 |                        | Mm2  |                |                                | SLTST lt-mgy, slcalc, arg, w/ wvy, cont bdg, sm xbd<br>SLTST ltgy-ltgrngy, sil, slcalc, sndy ip., w/ even,<br>cont bdg, intlaml w/ SH, dkgy, sil  |
|                                 | 7600                   |      |                |                                | SLTST aa  |
|                                 |                        | Mm1  |                |                                | SLTST m-dkgy, slcalc, arg, slsndy, bioturb ip.<br>SLTST mgy, slcalc, slarg, slsndy  |
|                                 | 20                     |      |                | 4958.4-<br>4958.0.4            | SLTST m-dkgy, fos (Brac, Crin), slcalc, slarg, sndy<br>SLTST aa   |
|                                 |                        | Lbs  |                |                                | SH dkgy, sil, slcarb, slty, slpyr, fis  |
|                                 | 40                     |      |                |                                |   |
|                                 |                        | TF   |                |                                |   |
|                                 | 7660                   |      |                |                                |   |



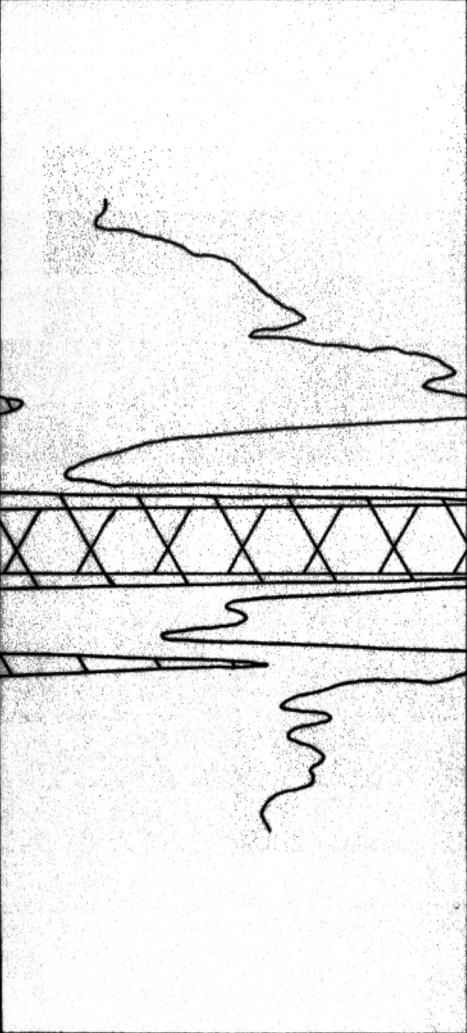
| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT        | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON                                | CORE DESCRIPTION--NDGS WELL NO. 5088<br>CORE DEPTH: 10156-10297' SIZE: 4" CONDITION: GOOD  |
|---------------------------------|------------------------|-------------|----------------|---|--|
|                                 | 10160                  | L           |                | 5088.43-<br>5088.39                                     | LS mgv. slfos (Crin), mic-vfxln, arg<br>SH dkgy-blk, fos ip. (Brac), sil-vslcalc, carb, sl-<br>silty, pyr, w/ abnt Cono<br>SH aa, unfos  |
|                                 |                        | Ubs         |                |   | SH dkgy-blk, sil, carb, vslsilty, pyr, fis<br>SH aa, vfos ip. (Brac), incr dkgy, slty  |
|                                 | 80                     | Mm3         |                | 5088.38-<br>5088.35.4                                   | SLTST ltgy, fos (Brac), slcalc, slpyr<br>SLTST lt-mgv, slfos, sil, slpyr, w/ even, cont bdg<br>SLTST lt-dkgy, slcalc, sndy ip., arg ip., sm bio-<br>turb, w/ disc bdg, sm xbdg<br>SS m-dkgy, vf-fgr, calc-vcalc, sbrnd, silty ip., w/<br>disc bdg, sm xbdg |
|                                 | 10200                  | Mm2         |                |   | SS m-dkgy, vf-fgr, calc, sbrnd, w/ even-slwy bdg<br>SLTST m-dkgy, calc, sndy, arg ip., w/ even-cont bdg<br>SLTST aa, decr sndy, incr calc  |
|                                 |                        |             |                | 5088.35.3<br>5088.35.2                                  | SLTST m-dkgy, fos (Plant), calc, sndy ip., arg ip.,<br>w/ even, cont bdg   |
|                                 | 20                     |             |                | 5088.35<br>5088.33-<br>5088.29                          | SLTST mgv, sil-slcalc, arg, sndy ip., bioturb ip.,<br>sm wvy bdg<br>SLTST mgv, slfos (Brac), slcalc, slsndy, bioturb   |
|                                 |                        | Mm1         |                | 5088.28.8<br>5088.28.6<br>5088.28                       | SLTST aa, incr fos, bioturb<br>SLTST mgv, slfos (Brac), slcalc-calc, slsndy, bio-<br>turb, w/ sm disc bdg  |
|                                 | 10240                  |             |                | 5088.27.6-<br>5088.23<br>5088.22<br>5088.21-<br>5088.17 | SLTST mgv, fos (Brac, Mol), calc, bioturb<br>SLTST aa<br>SLTST aa, vfos (Brac, Mol, Conch)   |
|                                 |                        | Lbs<br>(pt) |                |   | Lower black shale member on next page  |



| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY  | FOSSIL NOS.<br>& HORIZON      | CORE DESCRIPTION--NDGS WELL NO. 5088<br>CONTINUED FROM LAST PAGE |
|--|------------------------|------|---|-------------------------------|--|
|   | 10260-                 | Mml  |  | 5088.16<br>5088.15            | Upper two members of Bakken on preceding page                    |
|  |                        |      |   | 5088.14                       | SH dkgy, vfos (Conch), sil, carb, slsly, slpyr, fis              |
|  |                        |      |   | 5088.13<br>5088.12            | SH dkgy-blk, sil, carb, pyr, fis, w/ abnt Cono                   |
|  |                        | Lbs  |   |                               | SH dkgy, slfos (Ost), sil, slcarb, slsly, vpyr, fis              |
|  |                        | 80-  |   | 5088.11                       | SH aa, w/ Ceph   |
|  | 10300-                 |      |   | 5088.10                       | SH aa, w/ tr Brac  |
|  |                        |      |   | 5088.9-<br>5088.1<br>(12 pcs) | SH dkgy, fos (Brac, Conch, Ost), sil, slcarb, slpyr, fis         |
|  |                        | TF   |   |                               | SH ltgy, ltgrngy, mot, dolo                                      |
|  | 10320-                 |      |   |                               |  |

| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 7851<br>CORE DEPTH: 9386-9450' SIZE: 3½" CONDITION: GOOD         |
|--|------------------------|------|----------------|--------------------------|--|
|  | 9360                   |      |                |                          |  |
|  |                        | L    |                |                          |  |
|  |                        | Ubs  |                |                          |  |
|  | 80                     |      |                |                          |  |
|  |                        | Mm3  |                | 7851.2                   | SLTST mgy, fos (Brac), slcalc, intbdd w/ SH, dkgy, fos (Brac), sil, & SS, ltgy, fos (Brac), calc |
|  |                        | Mm2  |                | 7851.1                   | Intlam SH, SLTST, & SS, sil-calc, unfos, sm xbdg, w/ ?Plant                                      |
|  | 9400                   |      |                |                          | wvy, disc lams of SH, SLTST, & SS, aa  |
|  |                        | Mm1  |                |                          | SLTST lt-mgy, slfos (Brac), sil-slcalc, bioturb  |
|  |                        |      |                |                          | SLTST ltgy, vsifos (Brac), sil-calc, vbioturb  |
|  |                        |      |                |                          | SLTST lt-mgy, aa, incr Brac  |
|  | 20                     |      |                |                          |  |
|  |                        | Lbs  |                |                          |  |
|  | 40                     |      |                |                          |  |
|  |                        |      |                |                          | SH dkgy, sil, carb, asph ip., slsilty, pyr, fis  |
|  |                        |      |                |                          | SH aa  |
|  |                        | TF   |                |                          | SLTST mgy, dolo, arg   |
|  | 9460                   |      |                |                          |  |



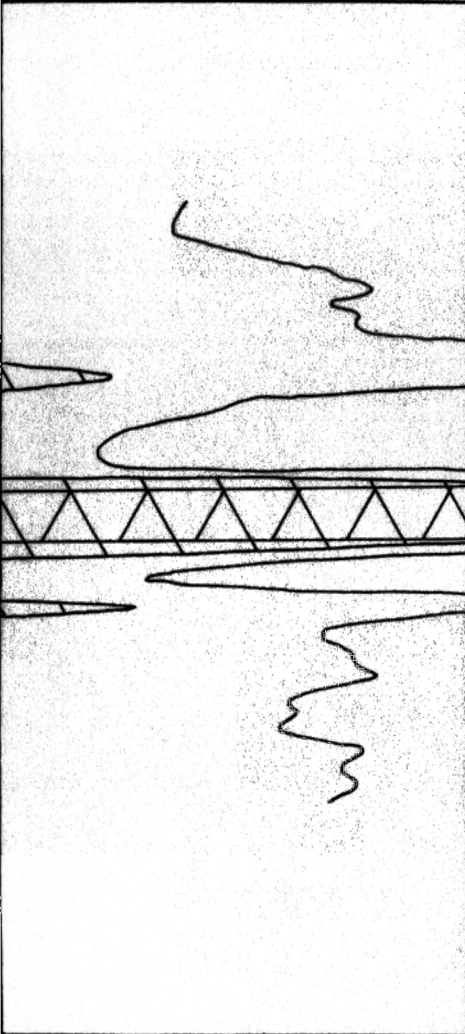
| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 7887<br>CORE DEPTH: 10786-10802' SIZE: 4" CONDITION: GOOD |
|--|------------------------|------|----------------|--------------------------|---|
|  | 10760-                 |      |                |                          |   |
|  | 80-                    |      |                |                          |   |
|  |                        | L    |                |                          | SH dkgy-blk, sil, carb, pyr, fis  |
|  |                        | Ubs  |                |                          | SH dkgy-blk, aa, w/ tr Conch  |
|  | 10800-                 | Mm3  |                | 7851.4-<br>=7851.2       | SH m-dkgy, fos (Brac), calc, slsilty, fis, grdg into                                      |
|  |                        | Mm2  |                |                          | LS, m-dkgy, fos, vfy in, slty   |
|  |                        | Lbs  |                |                          | SH mgy, unfos, calc-dolo, slty, sm disc bdg   |
|  |                        | TF   |                |                          | SH blk, sil, carb, pyr, fis   |
|  | 20-                    |      |                |                          | SLTST mgy, fos (Brac), calc, pyr  |
|  | 10840-                 |      |                |                          |   |





| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON  | CORE DESCRIPTION--NDGS WELL NO. 8069<br>CORE DEPTH: 9157-9211' SIZE: 4" CONDITION: GOOD         |
|---------------------------------|------------------------|------|----------------|---|---|
|                                 | 9160                   | L    |                |   | SH dkgy-blk, sil, carb, pyr, fis  |
|                                 |                        | Ubs  |                |   | SH aa   |
|                                 | 80                     | Mm3  |                | 8069.20-<br>8069.13.2<br>(12 pcs)                                 | SH dkgy-blk, aa   |
|                                 |                        | Mm2  |                |   | SLTST m-dkgy, fos (Brac), sil-slcalc, slpyr, int-<br>bdd w/ SS, ltgy, fos ip., vfgr, calc, slty |
|                                 |                        |      |                |   | SLTST m-dkgy, unfos, sil-calc, arg ip., sndy ip.,<br>even-wvy bdd, sm xbdg                      |
|                                 |                        |      |                |   | SLTST mgy, sil-slcalc, w/ wvy, disc bdg   |
|                                 |                        |      |                |   | SLTST aa, decr bdg  |
|                                 | 9200                   | Mm1  |                | 8069.13<br>8069.12<br>8069.11-<br>8069.9.4<br>(18 pcs)<br>8069.2- | SLTST lt-mgy, slfos (Brac), slcalc, sndy, slarg,<br>bioturb                                     |
|                                 |                        |      |                |   | SLTST aa, incr fos  |
|                                 |                        |      |                |   | SLTST mgy-mgrngy, fos (Brac, Mol), calc, slsndy,<br>slpyr, bioturb ip.                          |
|                                 | 20                     | Lbs  |                | 8069.0.2  | SH dkgy-blk, sil, carb, asph ip., pyr, fis  |
|                                 |                        |      |                |   | SH aa, vasph ip.  |
|                                 |                        |      |                |   | LS dkgy, vfxln, arg   |
|                                 | 9240                   | TF   |                |   |   |



| GAMMA RAY LOG<br>— 10 API UNITS | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 8177<br>CORE DEPTH: 8629-8667' SIZE: 3½" CONDITION: GOOD                                       |
|---------------------------------|------------------------|------|----------------|--------------------------|--|
|                                 | 8600                   |      |                |                          |  |
|                                 | 20                     | L    |                |                          |  |
|                                 |                        | Ubs  |                | 8177.5                   | SH blk, sil, carb, slpyr, fis<br>SH aa, incr pyr, w/ Plant<br>SH aa  |
|                                 | 40                     | Mm3  |                | 8177.4.6-<br>8177.2      | SLTST lt-mgy, fos (Brac), sil-calc, w/ wvy, disc<br>bdg, grdg into LS, ltgy, fos (Brac), vfxln, slty                           |
|                                 |                        | Mm2  |                |                          | SLTST lt-mgy, sil-calc, w/ even-wvy bdg, intlamm w/<br>SH, dkgy, sil   |
|                                 |                        | Mm1  |                |                          | LS ltgy, f-mxln, vsndy, slty ip., w/ even-wvy bdg  |
|                                 | 60                     | Lbs  |                |                          | SLTST ltgy, calc, arg<br>LS ltgy, silfos (Brac), vf-mxln, vslty, slsndy<br>LS ltgy, fos (Brac, Crin), vf-mxln, arg, slty, sndy |
|                                 |                        | TF   |                |                          | SH blk, sil, carb, pyr, fis<br>SH aa   |
|                                 | 80                     |      |                |                          |  |
|                                 | 8700                   |      |                |                          |  |

| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT      | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 8474<br>CORE DEPTH: 10359-10375' SIZE: 4" CONDITION: POOR   |
|--|------------------------|-----------|----------------|--------------------------|---|
|  | 10340                  |           |                |                          |   |
|  | 60                     | L         | L              |                          |   |
|  |                        | Ubs       | Ubs            |                          | LS m-dkgy, fos (Crin), vfxln, arg, slpyr<br>SH dkgy-blk, sil-vslcalc, carb, pyr, fis<br>SH aa, slfos (Conch)<br>SH aa, fos ip. (Brac) |
|  | 80                     | Mm3       | Mm3            | 8474.3-<br>8474.1        | SLTST m-dkgy, fos (Brac), sil-vcalc, w/ sm disc bdg<br>SLTST aa, decr fos, incr bdg   |
|  | 10400                  | Lbs<br>TF | Lbs<br>TF      |                          |   |



| GAMMA RAY LOG<br>— 10 API UNITS  | LOG<br>DEPTH<br>(feet) | UNIT | LITH-<br>OLOGY | FOSSIL NOS.<br>& HORIZON | CORE DESCRIPTION--NDGS WELL NO. 9351<br>CORE DEPTH: 10442-10480' SIZE: 4" CONDITION: GOOD              |
|--|------------------------|------|----------------|--------------------------|--|
|   | 10440-                 |      |                |                          |  |
|  | 60-                    | L    |                |                          | LS dkgy, fos (Coral, Crin), mic-vfxln  |
|  |                        | Ubs  |                |                          | SH dkgy-blk, sil, carb, pyr, fis   |
|  |                        | Mm3  |                | 9351.9<br>9351.6-        | SH aa, abnt Cono   |
|  |                        | Mm2  |                | 9351.2                   | SLTST dkgy, fos (Brac), sil-slcalc, varg ip., pyr,<br>sm bdg, intlamm w/ SS, ltgy, tr Brac, vcalc, fgr |
|  | 80-                    | Lbs  |                |                          | SLTST lt-dkgy, calc, intlamm w/ SS, ltgy, vfgr, calc   |
|  |                        | TF   |                |                          | SLTST m-dkgy, slcalc, w/ sm disc bdg   |
|  |                        |      |                |                          | SH blk, sil-vslcalc, fis   |
|  |                        |      |                |                          | SH mgrngy, lt-mgy, dolo  |
|  | 10500-                 |      |                |                          |  |

**APPENDIX 3**

## APPENDIX 3

## ENUMERATION OF COLLECTED FOSSILS

## ARRANGED BY WELL NUMBER AND DEPTH

The numbering system used in this enumeration is explained in the Materials and Methods section. Figured specimens (chirohypotypes) are indicated in the list by the catalog number given them in the paleontological collections of the Geology Department; these catalog numbers are preceded by the abbreviation, UND, and followed by a decimal point or period to distinguish this number from other serial collection numbers.

The abbreviation "c. p." stands for counterpart; the abbreviations for the stratigraphic units of the Bakken are given near the end of the introduction to Appendix 2.

## ENUMERATION OF COLLECTED FOSSILS

## ARRANGED BY WELL NUMBER AND DEPTH

NDGS Well No.

Mm3

- 105.1 Brachiopod cross sections
- 105.1.2 Chonetes gregarius, Torynifer sp.
- 105.2 Dissolved;
  - 105.2a-b Ostracods
  - 105.2c-e Pelmatozoan columnals
  - 105.2f-o Disarticulated (chonetid?) spines
  - 105.2p-q Foraminiferid fragments
- 105.3 Chonetes ornatus (c. p. of 105.4)
- 105.4 C. ornatus, Spirifer sp.
- 105.5 C. ornatus (UND 2754.), C. gregarius (UND 2749.), brachiopod spines

NDGS Well No. 207

Ubs

- 207.1 ?Paraconularia missouriensis (UND 2729.)

NDGS Well No

Mm3

- 413.1 ?C. ornatus (juvenile?)

Ubs

- 413.2 ?Rhytiophora arcuatus juvenile?)

NDGS Well No. 527

Lbs

- 527.1 Barroisella sp.



527.2      Syringopora Morphotype C (UND 2730.), Spirifer sp.

NDGS Well No. 607

Lbs

- 607.1      Lingula sp. 2, fish scale
- 607.2      Ostracod
- 607.2.2    Ostracod (c. p. of 607.2)
- 607.3      Lingula sp. 2, fish scale
- 607.4      Lingula sp. 2 (UND 2732.), Barroisella sp.
- 607.5      Lingula sp. 2 (UND 2733.), fish scale
- 607.5.2    Fish scale
- 607.5.4    Fish scale (c. p. of 607.5.2)
- 607.6      Fish scale (UND 2798.)
- 607.7      Large ostracod
- 607.8      Fish scale

Mm1

- 607.8.4    Syringothyris hannibalensis (UND 2770.)
- 607.8.6    Orthocerid nautiloid
- 607.8.8    Orthocerid nautiloid (c. p. of 607.8.6)
- 607.9      Scalarituba missouriensis, Tylothyris clarksvillensis
- 607.9.2    Planolites sp.
- 607.9.4    Planolites sp. (c. p. of 607.9.2)

Mm2

- 607.10     Bladelike leaves
- 607.11     Bladelike leaves

Mm3

- 607.11.2   ?Allorhyncus acutiplicum (UND 2764.)

607.11.4 ?A. acutiplicum (c. p. of 607.11.2)

607.11.6 ?A. heteropsis

Ubs

607.12 Cyzicus (Lioestheria) sp

607.13 ?Orbiculoidea limata (juvenile?), pelmatozoan columnals (c. p of 607.14)

607.14 C. (Lioestheria) sp., ?O. limata, indeterminate gastropod, pelmatozoan columnals, ?pelecypod

607.15 C. (Lioestheria) sp. (UND 2794.

NDGS Well No. 999

Mm

999.2 Brachiopod cross sections

NDGS Well No. 1405

Lbs

1405.2 Asphaltic blebs

Mm1

1405.3 Schellweinella inflata (c. p. of 1405.4)

1405.4 S. inflata (UND 2745.)

NDGS Well No. 1679

Lbs

1679.1 Rugaltarostrum madisonense (UND 2762.)

NDGS Well No. 2226

Lbs

2226.1 Spirophyton-like trace fossil (UND 4352.

NDGS Well No. 2383

Lbs

- 2383.0.4 R. madisonense (UND 2761.), Straparollus (Straparollus)  
sp. 2 (UND 2783.
- 2383.0.6 R. madisonense, S. (Straparollus) sp. 2, (c. p. of 2383.0.4)  
indeterminate pelecypod  
R. madisonense, Lingula sp. 2, costate rhynchonellid brach-  
iopod
- 2383.2 R. madisonense, costate rhynchonellid brachiopod (c. p. of  
2383.1); Barroisella sp., indeterminate pelecypod
- 2383.4 Coiled cephalopod (UND 2787.), S. (Straparollus) sp. 2,  
Cyzicus (Lioestheria) sp.
- 2383.5 Lingula sp. 2, coiled cephalopod, S. (Straparollus) sp. 2,  
Cyzicus (Lioestheria) sp. (c. p. of 2383.4)
- 2383.6 Phragmosphaera sp. (UND 2781.), S. (Straparollus) sp. 2,  
orthocerid nautiloid, C. (Lioestheria) sp., ostracod
- 2383.7 Phragmosphaera sp., S. (Straparollus) sp. 2, orthocerid  
nautiloid, C. (Lioestheria) sp., ostracod, (c. p. of 2383.6)  
Barroisella sp., pelecypod
- 2383.8 Lingula sp. 2, S. (Straparollus) sp. 2, coiled cephalopod  
C. (Lioestheria) sp
- 2383.9 Lingula sp. 2 (c. p. of 2383.8)
- 2383.10 Lingula sp. 2, Barroisella sp.
- 2383.10.2 Lingula sp. 2, Barroisella sp. (UND 2736. & UND 2737.),  
hylothyrid (c. p. of 2383.10 and 2383.11
- 2383.1 Lingula sp. 2, Barroisella sp., hylothyrid
- 2383.12 S. (Straparollus) sp. 2, Cyzicus (Lioestheria) sp., ostracod
- 2383.13 S. (Straparollus) sp. 2, C. (Lioestheria) sp., ostracods

(c. p. of 2383.12); pelecypod

- 2383.14 S. (Straparollus) sp. 2, C. (Lioestheria) sp
- 2383.16 Lingula sp. 2, ostracods
- 2383.17 Barroisella sp., indeterminate spinules
- 2383.18 Barroisella sp., indeterminate spinules (c. p. of 2383.17)

NDGS Well No. 2618

Mm1

- 2618.1 Syringothyris hannibalensis

Mm3

- 2618.2 Rhytiophora arcuatus
- 2618.3 Orbinaria pyxidata, ?Allorhynchus heteropsis, Composita sp. 2  
(UND 2766.), ostracods, spines
- 2618.4 Composita sp. 2, spines (c. p. of 2618.3)

NDGS Well No. 2967

Lbs

- 2967. Cyzicus (Lioestheria) sp. (UND 2792.
- 2967.2 C. (Lioestheria) sp. (UND 2795.)

Mm1

- 2967.4 ?Rhipidomella missouriensis juvenile?)
- 2967.5 Dissolved;

2967.5b-q Straparollus (Straparollus) sp. 1 (UND 2782.

2967.5r-bb Juvenile brachiopods

2967.5cc-hh Juvenile brachiopods (UND 2780.)

2967.5ii-tt Minute burrows

2967.5uu Brachiopod spine?

2967.5vv Juvenile brachiopod

2967.5ww-xx ?Imitoceras sp.

- 2967.6 ?Rhipidomella missouriensis juvenile?)
- 2967.7 R. missouriensis, Schellweinella inflata, Tylothyris clarksvillensis
- 2967.8 T. clarksvillensis
- 2967.9 R. missouriensis (UND 2743.)
- 2967.10 T. clarksvillensis, Scalarituba missouriensis
- 2967.11 Orthocerid nautiloid (UND 2786.)
- 2967.11.4 R. missouriensis, T. clarksvillensis (UND 2768.)
- 2967.11.6 R. missouriensis (c. p. of 2967.11.4)
- 2967.12 R. missouriensis (UND 2742.), Schellweinella inflata

## Mm2

- 2967.13 Bladelike leaves (UND 4345.)
- 2967.13.2 Bladelike leaves
- 2967.14 Chondrites sp. (UND 4348.)

## Mm3

- 2967.15 Orbinaria pyxidata (UND 2756.), ?Allorhynchus heteropsis
- 2967.16 O. pyxidata (UND 2757.)
- 2967.17 ?A. heteropsis

## NDGS Well No. 3167

## Mm1

- 3167.1 Dissolved;
- 3167.1a Immature productid
- 3167.1b Minute burrow
- 3167.1. Schuchertella lens
- 3167.1.4 Syringothris hannibalensis
- 3167.1.5 Rhipidomella missouriensis (UND 2741.), S. hannibalensis

3167.2.4 Scalarituba missouriensis

3167.2.8 Syringothyris hannibalensis (UND 2769.

Mm3

3167.3 Chonetes gregarius, Orbinaria pyxidata, spines

3167.4 C. gregarius, O. pyxidata (c. p. of 3167.3); Spirifer sp.

NDGS Well No. 3363

Lbs

3363.4 Large ostracod

NDGS Well No. 4264

Lbs

4264.1 Large ostracod

NDGS Well No. 4297

Ubs

4297.1 Cyzicus (Lioestheria) sp.

4297.2 C. (Lioestheria) sp

NDGS Well No. 4340

Lbs

4340.0.2 Foerstia sp. (UND 2799.)

4340.0.4 Foerstia sp.

4340.1 Foerstia sp. (UND 4344.)

4340.2 Large ostracod

4340.3 Large ostracod (UND 2796.

4340.4 Plant stem

Mm1

4340.5 Schuchertella lens

- 4340.6      Pelmatozoan column
- 4340.6.2    Rhipidomella missouriensis juvenile), grammysian pelecypod  
(UND 2789.), arthropod fragment, ostracod
- 4340.6.4    Tylothyris clarksvillensis, grammysian pelecypod, pelmatozoan  
column, ostracod
- 4340.7      T. clarksvillensis (UND 2767.)
- 4340.8      Rhipidomella missouriensis
- 4340.10     Cosmoraphe sp., Planolites sp. (UND 4350.), Scalarituba  
missouriensis
4340.       Syringothyris hannibalensis
- 4340.12     S. hannibalensis (c. p. of 4340.12)
- Mm3
- 4340.13     ?Allorhynchus heteropsis, Composita sp., Spirifer sp.
- 4340.13.2   Composita sp. 1 (UND 2765.
- 4340.14     Orbinaria pyxidata, Rhytiophora arcuatus, ?A. heteropsis,  
Composita sp. 1, Spirifer sp., indeterminate pelecypod
- 4340.15     R. arcuatus, ?A. heteropsis, indeterminate brachiopod
- Ubs
- 4340.16     Large ostracod, ostracod
- 4340.17     Ostracod (c. p. of 4340.16)

NDGS Well No. 4508

Mm

- 4508.1      Rhipidomella missouriensis, Schellweinella inflata

NDGS Well No. 4958

Mm1

- 4958.0.4    Schuchertella lens, ?Allorhynchus heteropsis, Tylothyris



clarksvillensis, Loxonema cf. L. missouriensis (UND 2784.

- 4958.0.6 Orbiculoidea limata (UND 2738.), Schellweinella inflata,  
indeterminate rhynchonellid, indeterminate brachiopod, arth-  
ropod fragment
- 4958.1 R. missouriensis (UND 2740.), pelmatozoan column
- 4958.2 R. missouriensis, Cosmoraphe sp.
- 4958.3 Rhytiophora arcuatus
- 4958.4 Pelmatozoan column
- Mm3
- 4958.6 Spirifer greenockensis (UND 2775.), Spirifer sp., ?trilobite  
pleuron
- 4958.6.2 S. greenockensis, Spirifer sp. (c. p. of 4958.6 & 4958.7)
- 4958.7 Rhytiophora arcuatus, Syringothyris halli, Spirifer green-  
ockensis (UND 2776.), Spirifer sp. (c. p. of 4958.6 & 4958.8)
- 4958.8 Chonetes gregarius, R. arcuatus, Syringothyris halli (UND  
2773.), Spirifer sp.
- 4958.9 C. gregarius (UND 2747.), Spirifer sp.
- 4958.9.2 C. gregarius, R. arcuatus, Spirifer sp.
- 4958.10 C. gregarius, C. ornatus , R. arcuatus, Syringothyris halli,  
Spirifer sp. (UND 2778.
- 4958.10.2 S. halli (c. p. of 4958.10)
- 4958.11 C. gregarius, C. ornatus, R. arcuatus, S. halli, Spirifer sp  
(c. p. of 4958.10)
- 4958.12 Lingula sp. 4, C. gregarius (UND 2750.), C. ornatus (UND  
2751.), S. greenockensis
- 4958.13 Spirifer sp.
- 4958.14 Spirifer sp.

## NDGS Well No. 5088

## Lbs

- 5088.1      ?Arthropod fragment
- 5088.1.2   Lingula sp. 2
- 5088.2      Cyzicus (Lioestheria) sp.
- 5088.3      C. (Lioestheria) sp. (c. p. of 5088.2)
- 5088.4      C. (Lioestheria) sp.
- 5088.5      C. (Lioestheria) sp. (c. p. of 5088.4)
- 5088.6      C. (Lioestheria) sp. (c. p. of 5088.5)
- 5088.7      C. (Lioestheria) sp. (c. p. of 5088.6)
- 5088.7.2    C. (Lioestheria) sp. (UND 2791.)
- 5088.7.4    C. (Lioestheria) sp. (c. p. of 5088.7.2)
- 5088.8      C. (Lioestheria) sp., large ostracod
- 5088.9      C. (Lioestheria) sp. (UND 2793.-- c. p. of 5088.8)
- 5088.10     Lingula sp. 3 (UND 2734.)
- 5088.11     Large ostracod
- 5088.11.2   Large ostracod
- 5088.12     Orthocerid nautiloid (c. p. of 5088.13)
- 5088.13     Orthocerid nautiloid (UND 2785.)
- 5088.14     Large ostracod
- 5088.15     Indeterminate eumalacostracan (c. p. of 5088.16)
- 5088.16     Indeterminate eumalacostracan (UND 2797.)

## Mm1

- 5088.17     Indeterminate brachiopod, orthocerid nautiloid, C. (Lio-  
estheria) sp.
- 5088.18     Orthocerid nautiloid
- 5088.19     Orbinaria pyxidata, orthocerid nautiloid, C. (Lioestheria)

- sp. (c. p. of 5088.17)
- 20 Juvenile chonetid?
- 20.2 Grammysian? pelecypod
- 5088.21 Dissolved;  
5088.21a Foraminiferid fragment
- 5088.22 Dissolved;  
5088.22a Rhipidomella missouriensis  
5088.22b-d Minute burrows
- 5088.23 O. pyxidata
- 5088.24 Scalarituba missouriensis (UND 4351.
- 5088.25 Rhipidomella missouriensis
- 5088.26 R. missouriensis
- 5088.27 R. missouriensis
- 5088.27.4 R. missouriensis, Tylothyris clarksvillensis
- 5088.27.5 R. missouriensis, T. clarksvillensis (c. p. of 5088.27.4)
- 5088.27.6 Syringothyris hannibalensis
- 5088.28 Scalarituba missouriensis
- 5088.28.6 R. missouriensis, Syringothyris hannibalensis (UND 2771.)
- 5088.28.8 T. clarksvillensis, Cosmoraphe sp. (UND 4349.
- 5088.29 Dissolved;  
5088.29a Foraminiferid fragment
- 5088.31 Syringothyris hannibalensis
- 5088.32 Scalarituba missouriensis
- 5088.33 Rhipidomella missouriensis
- 5088.35 Planolites sp.
- Mm2
- 5088.35.2 Bladelike leaves

5088.35.3 Bladelike leaves (c. p. of 5088.35.2)

Mm3

5088.35.4 Orbiculoidea limata, Chonetes ornatus

5088.35.6 O. limata (c. p. of 5088.35.4)

5088.36 Spirifer greenockensis

js

5088.38 R. missouriensis

5088.39 ?C. ornatus juvenile?)

5088.40 ?C. ornatus (c. p. of 5088.39); Lingula sp.

5088.41 Lingula sp. 1 (UND 2731.), ?C. ornatus (c. p. of 5088.40)

5088.42 Lingula sp. 1, ?C. ornatus

5088.43 Lingula sp. 1, ?C. ornatus, Cyzicus (Lioestheria) sp

5088.44 Lingula sp. 1, C. (Lioestheria) sp.

NDGS Well No. 7851

Mm2

7851. Plant stems (UND 4346.)

Mm3

7851.2 Chonetes gregarius

NDGS Well No. 7887

Mm3

7887.2 Orbiculoidea limata, C. gregarius, Spirifer sp.

brachiopod cross sections, ?arthropod fragment

7887.3 C. gregarius, Orbinaria pyxidata, Rhytiophora arcuatus

Ubs

7887.4 Cyzicus (Lioestheria) sp.

NDGS Well No. 8069

Lbs

8069.0.2 Asphaltic blebs

8069.0.4 Asphaltic blebs

Mm1

8069.1 Straparollus (Straparollus) sp. 1, prothyrid pelecypod  
(UND 2728.)

8069.2 Orthocerid nautiloid

8069.4 Rhipidomella missouriensis

8069.4.2 Plant stem

8069.4.3 Syringothyris hannibalensis, pelmatozoan column8069.4.5 S. hannibalensis (UND 2772.), orthocerid nautiloid8069.4.6 Orbiculoidea limata, Rhytiophora arcuatus, brachiopod spines

8069.4.7 O. limata, R. arcuatus (c. p. of 8069.4.6); ?Allorhynchus  
heteropsis

8069.4.8 Rhipidomella missouriensis

8069.4.9 R. missouriensis (c. p. of 8069.4.8); Rhytiophora arcuatus  
(UND 2759.)

8069.5 Rhytiophora arcuatus (c. p. of 8069.4.9)8069.6 R. arcuatus (c. p. of 8069.7 & 8069.8)8069.7 R. arcuatus (UND 2758.)8069.8 R. arcuatus8069.9.2 Rhipidomella missouriensis8069.10 Schuchertella lens8069.11 Lingula sp. 4 (UND 2735.)8069.12 Schuchertella lens (UND 2746.)8069.13 S. lens

- 8069.13.2 Plant stem
- 8069.13.4 Rhytiophora arcuatus (UND 2760.), ?Allorhynchus heteropsis
- 8069.14 R. arcuatus, ?A. heteropsis
- 8069.16 Chonetes gregarius, Rugosochonetes sp. (UND 2755.), Spirifer sp., Torynifer sp. (UND 2779.
- 8069.16.2 Syringothyris halli
- 8069.16.4 C. gregarius, S. halli (UND 2774.)
- 8069.16.6 C. gregarius, Spirifer sp., Torynifer sp.
- 8069.16.8 C. gregarius (UND 2752.), C. ornatus (UND 2753.
- 8069.17 C. gregarius, C. ornatus, brachiopod spines, pelmatozoan columnals, Brachymetopus (Brachymetopus) sp. (UND 2790.  
portion dissolved;
- 8069.17a Minute burrow
- 8069.17b-g Brachiopod spines?
- 8069.18 C. gregarius
- 8069.19 Orbiculoidea limata (UND 2739.), C. gregarius
- 8069.20 Rhipidomella missouriensis (UND 2744.), C. ornatus

NDGS Well No. 8177

Mm3

- 8177.2 Orbinaria pyxidata, ?Allorhynchus heteropsis
- 8177.3 ?A. heteropsis (UND 2763.)
- 8177.4 ?A. heteropsis
- 8177.4.2 Spirifer sp.
- 8177.4.4 Spirifer sp.
- 8177.4.6 Spirifer sp.

Ubs

- 8177.5 Woody plant fragment (UND 4347.

NDGS Well No. 8474

Mm3

8474.1     Spirifer sp.

8474.2     Spirifer sp. (c. p. of 8474. & 8474.3)

8474.3     Spirifer sp.

NDGS Well No. 9351

Lbs

9351.1     Indeterminate brachiopod

Mm3

9351.2     Orbinaria pyxidata

9351.3     Spirifer greenockensis

9351.4     ?Torynifer sp.

9351.5     Rhipidomella missouriensis

9351.6     R. missouriensis

9351.9     Chonetes ornatus



#### **APPENDIX 4**

## APPENDIX 4

CODE NUMBERS OF FOSSILS ARRANGED  
BY TAXA AND STRATIGRAPHIC SETTING

Explanations of abbreviations and the numbers used herein are given near the end of the introduction to Appendix 2 and in the introduction to Appendix 3.

---

CODE NUMBERS OF FOSSILS ARRANGED  
BY TAXA AND STRATIGRAPHIC SETTING

| TAXON  | UNIT | CODE NUMBERS  |
|--|------|---|
| <b>Protista</b>                                |      |   |
| Foraminiferida                                 | Mm1  | 5088.21a, 5088.29a<br>105.2p-q  |
| <b>Animalia</b>                                |      |   |
| <b>Coelenterata</b>                            |      |   |
| Hylothyrid                                     | Lbs  | 2383.10.2, 2383.  |
| ? <u>Paraconularia</u><br><u>missouriensis</u> | Ubs  | 207. (UND 2729.)  |
| <u>Syringopora</u> sp.                         | Mm2  | 527.2 (UND 2730.)   |
| <b>Brachiopoda</b>                             |      |   |
| <u>Lingula</u> sp. 1                           | Ubs  | 5088.40, 5088.4 (UND 2731.), 5088.42,<br>5088.43, 5088.44   |
| <u>Lingula</u> sp. 2                           | Lbs  | 607.1, 607.3, 607.4 (UND 2732.), 607.5,<br>(UND 2733.), 2383.1, 2383.5, 2383.8, 2383.9,<br>2383.10, 2383.10.2, 2383.11, 2383.16, 5088.1.2 |
| <u>Lingula</u> sp. 3                           | Lbs  | 5088.10 (UND 2734.)   |
| <u>Lingula</u> sp. 4                           | Mm1  | 8069.11 (UND 2735.<br>4958.12   |
| <u>Barroisella</u> sp.                         | Lbs  | 527.1, 607.4, 2383.2, 2383.7, 2383.10,<br>2383.10.2 (UND 2736. & UND 2737.), 2383.11,<br>2383.17, 2383.18                                 |
| <u>Orbiculoidea</u> <u>limata</u>              | Mm1  | 4958.0.6 (UND 2738.), 8069.4.6, 8069.4.7<br>5088.35.4, 5088.35.6, 7887.2, 8069.19<br>(UND 2739.   |

|   |     |  |
|---|-----|--|
|   | Ubs | 607.13, 607.14   |
| <u>Rhipidomella</u><br><u>missouriensis</u> | Mm1 | 2967.4, 2967.6, 2967.7, 2967.9<br>(UND 2743.), 2967. .4, 2967. .6, 2967.12<br>(UND 2742.), 3167.1.5 (UND 2741.), 4340.6.2,<br>4340.8, 4508.1, 4958. (UND 2740.), 4958.2,<br>5088.22, 5088.25, 5088.26, 5088.27,<br>5088.27.4, 5088.27.5, 5088.28.6, 5088.33,<br>8069.4, 8069.4.8, 8069.4.9, 8069.9.2<br>8069.20 (UND 2744.), 9351.5, 9351.6<br>5088.38 |
| <u>Schellweinella</u><br><u>inflata</u>     | Mm  | 1405.3, 1405.4 (UND 2745.), 2967.7<br>2967.12, 4508.1, 4958.0.6  |
| <u>Schuchertella</u> <u>lens</u>            | Mm1 | 3167.1, 4340.5, 4958.0.4, 8069.10,<br>8069.12 (UND 2746.), 8069.13   |
| <u>Chonetes</u> <u>gregarius</u>            | Mm3 | 105.1.2, 105.5 (UND 2749.), 3167.3,<br>3167.4, 4958.8, 4958.9 (UND 2747.), 4958.9.2,<br>4958.10, 4958. 4958.12 (UND 2748. & UND<br>2750.), 7851.2, 7887.2, 7887.3, 8069.16,<br>8069.16.4, 8069.16.6, 8069.16.8 (UND 2752.),<br>8069.18, 8069.19  |
| <u>Chonetes</u> <u>ornatus</u>              | Mm3 | 105.3, 105.4, 105.5 (UND 2754.), 413.1,<br>4958.10, 4958.11, 4958.12 (UND 2751.),<br>5088.35, 8069.16.8 (UND 2753.), 8069.17<br>8069.20, 9351.9<br>5088.39, 5088.40, 5088.41, 5088.42, 5088.43   |
| <u>Rugosochonetes</u> sp.                   | Mm3 | 8069.16 (UND 2755.)  |
| <u>Orbinaria</u> <u>pyxidata</u>            | Mm1 | 5088.19, 5088.23   |

|                                    |     |  |
|------------------------------------|-----|--|
|                                    |     | 2618.3, 2967.15 (UND 2756.), 2967.16<br>(UND 2757.), 3167.3, 3167.4, 4340.14<br>7887.3, 8177.2, 9351.2   |
| <u>Rhytiophora arcuatus</u>        | Mm1 | 4958.3, 8069.4.6, 8069.4.7, 8069.4.9<br>UND 2759.), 8069.5, 8069.6, 8069.7<br>(UND 2758.), 8069.8<br>2618.2, 4340.14, 4340.15, 4958.7, 4958.8,<br>4958.10, 4958.11, 7887.3, 8069.13.4<br>(UND 2760.), 8069.14<br>413.2 |
| <u>Rugaltarostrum madisonense</u>  | Lbs | 1679.1 (UND 2762.), 2383.0.4<br>(UND 2761.), 2383.0.6, 2383.1, 2383.2  |
| ? <u>Allorhynchus heteropsis</u>   | Mm3 | 607.11.6, 2618.3, 2967.15, 2967.17,<br>4340.13, 4340.14, 4340.15, 8069.13.4,<br>8069.14, 8177.2, 8177.3 (UND 2763.), 8177.4  |
| ? <u>A. acutiplicum</u>            | Mm3 | 607. .2 (UND 2764.), 607.11.4  |
| Indeterminate rhynchonellids       | Lbs | 2383.1, 2383.2<br>4958.0.4, 4958.0.6, 8069.4.7   |
| <u>Composita</u> sp. 1             | Mm3 | 4340.13, 4340.13.2 (UND 2765.  |
| <u>Composita</u> sp. 2             | Mm3 | 2618.3 (UND 2766.), 2618.4   |
| <u>Tylothyris clarks-villensis</u> | Mm  | 607.9, 2967.7, 2967.8, 2967.10,<br>2967.11.4 (UND 2768.), 4340.6.4, 4340.7<br>(UND 2767.), 4958.0.4, 5088.27.4, 5088.27.5,<br>5088.28.8, 8069.9  |
| <u>Syringothyris hannibalensis</u> | Mm1 | 607.8.4 (UND 2770.), 2618.1,<br>3167.1.4, 3167.1.5, 3167.2.8 (UND 2769.<br>4340.11, 4340.12, 5088.27.6,  |

|   |     |   |
|---|-----|---|
|   |     | 5088.28.6 (UND 2771.), 5088.31,<br>8069.4.3, 8069.4.5 (UND 2772.  |
| <u>Syringothyris halli</u>                                    | Mm3 | 4958.7, 4958.8 (UND 2773.), 4958.10,<br>4958.10.2, 4958.11, 8069.16.2, 8069.16.4<br>(UND 2774.)   |
| <u>Spirifer</u><br><u>greenockensis</u>                       | Mm3 | 4958.6 (UND 2775. & UND 2777.)<br>4958.6.2, 4958.7 (UND 2776.), 4958.12<br>5088.36, 9351.3  |
| <u>Spirifer</u> sp.   | Mm2 | 527.2<br><br>105.4, 3167.4, 4340.13, 4340.14, 4958.6<br>4958.6.2, 4958.7, 4958.8, 4958.9, 4958.9.2<br>4958.10 (UND 2778.), 4958.11, 4958.13,<br>4958.14, 7887.2, 8069.16, 8069.16.6,<br>8177.4.2, 8177.4.4, 8177.4.6, 8474.1,<br>8474.2, 8474.3 |
| <u>Torynifer</u> sp.  | Mm3 | 105.2, 8069.16 (UND 2779.), 8069.16.6,<br>9351.4  |
| Indeterminate<br>brachiopods                                  | Lbs | 9351.1<br><br>999.2, 2967.5 (UND 2780.), 4958.0.6, 5088.17<br>105.1, 4340.15  |
| Mollusca  |     |   |
| <u>Phragmosphaera</u> sp.                                     | Lbs | 2383.6 (UND 2781.), 2383.7  |
| <u>Straparollus</u> ( <u>Strap-</u><br><u>arollus</u> ) sp. 1 | Mm1 | 2967.5b-q (UND 2782.), 8069.1   |
| <u>S.</u> ( <u>Straparollus</u> )<br>sp. 2                    | Lbs | 2383.0.4 (UND 2783.), 2383.0.6, 2383.4,<br>2383.5, 2383.6, 2383.7, 2383.8, 2383.12,<br>2383.13, 2383.14   |
| <u>Loxonema</u> cf. <u>L.</u>                                 | Lbs | 4958.0.4 (UND 2784.)  |

missouriensis

|   |     |  |
|---|-----|--|
| Indeterminate gastropod                           | Ubs | 607.14   |
| Orthocerid nautiloid                              | Lbs | 2383.6, 2383.7, 5088.12, 5088.13 (UND 2785.),<br>607.8.6, 607.8.8, 2967.11 (UND 2786.),<br>5088.17, 5088.18, 5088.19, 8069.2, 8069.4.5 |
| ? <u>Imitoceras</u> sp.                           | Mm1 | 2967.5 <del>ww</del> -xx   |
| Indeterminate coiled cephalopod                   | Lbs | 2383.4 (UND 2787.), 2383.5, 2383.8   |
| Grammysians                                       | Mm1 | 4340.6.2 (UND 2789.), 4340.6.4, 5088.20.2  |
| Prothyrid   | Mm1 | 8069.1 (UND 2788.)   |
| Indeterminate pelecypods                          | Lbs | 2383.0.6, 2383.2, 2383.7, 2383.13<br>4340.14   |
|   | Ubs | 607.14   |
| Arthropoda  |     |  |
| <u>Brachymetopus</u> ( <u>Brachymetopus</u> ) sp. | Mm3 | 8069.17 (UND 2790.)  |
| Ostracods   | Lbs | 607.1, 607.2, 607.2.2, 2383.6<br>2383.7, 2383.12, 2383.13, 2383.16<br>4340.6.2<br>105.2, 2618.3<br>4340.16, 4340.17                    |
| Large ostracod                                    | Lbs | 607.7, 3363.4, 4264.1, 4340.2,<br>4340.3 (UND 2796.), 5088.8, 5088.11,<br>5088.11.5, 5088.14<br>4340.16                                |
| <u>Cyzicus</u> ( <u>Lioestheria</u> ) sp.         | Lbs | 607.1, 2383.4, 2383.5, 2383.6,<br>2383.7, 2383.8, 2383.12, 2383.13, 2383.14,   |



|  |     |   |
|--|-----|---|
|  |     | 2967.1 (UND 2792.), 2967.2 (UND 2795.       |
|  |     | 5088.2, 5088.3, 5088.4, 5088.5, 5088.6      |
|  |     | 5088.7, 5088.7.2 (UND 2791.), 5088.7.4      |
|  |     | 5088.7.4, 5088.8, 5088.9 (UND 2793.)        |
|  | Mm1 | 5088.17, 5088.19                            |
|  |     | 607.12, 607.14, 607.15 (UND 2794.), 4297.1, |
|  |     | 4297.2, 5088.43, 5088.44, 7887.4            |
| Indeterminate<br>eumalacostracan       | Lbs | 5088.15, 5088.16 (UND 2797.)                |
| Indeterminate arth-<br>ropod fragments | Lbs | 5088.1                                      |
|  | Mm1 | 4340.6.2, 4958.0.6                          |
|  | Mm3 | 4958.6, 7887.2                              |
| Echinodermata                          |     |   |
| Pelmatozoan<br>fragments               | Mm1 | 4340.6, 4340.6.4, 4958.1, 4958.4, 8069.4.3  |
|  | Mm3 | 105.2, 8069.17                              |
|  | Ubs | 607.13, 607.14                              |
| Chordata                               |     |   |
| Fish Fragments                         | Lbs | 607.3, 607.5, 607.5.2, 607.6                |
|  |     | (UND 2798.), 607.8                          |
| Plantae                                |     |   |
| <u>Foerstia</u> sp.                    | Lbs | 4340.0.2 (UND 2799.), 4340.0.4,             |
|  |     | 4340.1 (UND 4344.)                          |
| Bladelike leaves                       | Mm2 | 607.10, 607.11, 2967.13 (UND 4345.),        |
|  |     | 2967.13.2, 5088.35.2, 5088.35.3             |
| Plant stems                            | Lbs | 4340.4                                      |
|  |     | 8069.4.2                                    |
|  |     | 7851.1 (UND 4346.), 8069.13.2               |
|  |     | 8177.5 (UND 4347.)                          |

## Ichnofossils

|  |     |   |
|--|-----|---|
| <u>Chondrites</u> sp.                      | Mm2 | 2967.14 (UND 4348.  |
| <u>Cosmoraphe</u> sp.                      | Mm  | 4340.10, 4958.2, 5088.28.8 (UND 4349.                                       |
| <u>Planolites</u> sp.                      | Mm1 | 607.9.2, 607.9.4, 4340.10 (UND 4350.),<br>5088.35                           |
| <u>Scalarituba</u><br><u>missouriensis</u> | Mm1 | 607.9, 2967.10, 3167.2.4, 4340.10,<br>5088.24 (UND 4351.), 5088.28, 5088.32 |
| <u>Spirophyton-like</u><br>trace fossil    | Lbs | 2226.1 (UND 4352.)  |

## BIBLIOGRAPHY

- Achauer, C. W., 1959, Stratigraphy and microfossils of the Sappington Formation in southwestern Montana: Billings Geological Society, 10th Annual Field Conference Guidebook, p. 41-49.
- Ballard, F. V., 1963, Structural and stratigraphic relationships in the Paleozoic rocks of eastern North Dakota: North Dakota Geological Survey Bulletin 40, p. 17-18.
- Bjorlie, P. F., 1979, The Carrington shale facies (Mississippian) and its relationship to the Scallion subinterval in central North Dakota: North Dakota Geological Survey Report of Investigation No. 67, 46 p.
- Boucout, A. J., Johnson, J. G., and Staten, R. D., 1965, Suborder Athyrididina, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. H654-H667.
- Branson, E. B., 1938, Stratigraphy and paleontology of the Lower Mississippian of Missouri, parts 1 and 2: University of Missouri Studies, v. 13, no. 3, 372 p., 48 pl.
- Brindle, J. E., 1960, Mississippian megafaunas in southeastern Saskatchewan: Saskatchewan Department of Mineral Resources Report 45, 107 p., 29 pl.
- Brooks, H. K., 1962, The Paleozoic Eumalacostraca of North America: Bulletins of American Paleontology, v. 44, p. 163-338, 66 pl.
- Brooks, H. K., 1969, Palaeostomatopoda, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part R, Arthropoda 4, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. R533-R535.
- Brown, R. A. C., 1952, Carboniferous stratigraphy and paleontology in the Mt. Greenock area, Alberta: Geological Survey of Canada Memoir 264, 119 p., 5 pl.
- Byers, C. W., 1977, Biofacies patterns in euxinic basins: a general model: Society of Economic Paleontologists and Mineralogists, Special Publication, no. 25, p. 5-17.
- Campbell, Guy, 1946, New Albany Shale: Geological Society of America Bulletin, v. 57, p. 829-908, 3 pl.

- Carlson, C. G., and Anderson S. B., 1970, Sedimentary and tectonic history of North Dakota part of the Williston basin: North Dakota Geological Survey Misc. Series No. 28, reprinted from, American Association of Petroleum Geologists Bulletin, 1965, v. 49, no. 11, p 1833-1846.
- Carter, J. L., and Carter, R. C., 1970, Bibliography and index of North American Carboniferous brachiopods (1898-1968): Geological Society of America Memoir 128, 382 p.
- Christopher, J. E., 1961, Transitional Devonian-Mississippian formations of southern Saskatchewan: Saskatchewan Department of Mineral Resources Report 66, 103 p., 4 pl.
- Christopher, J. E., 1962, The Three Forks Group (Upper Devonian-Kinderhookian) of southern Saskatchewan: 13th Annual Field Conference Guidebook, Billings Geological Society, p. 67-77.
- Collinson, C. W., 1961, The Kinderhookian series in the Mississippi Valley: Kansas Geological Society Guidebook, 26th Annual Field Conference, northeastern Missouri and west-central Illinois, p. 100-109.
- Conkin, J. E., and Conkin, B. M., 1968, Scalarituba missouriensis and its stratigraphic distribution: University of Kansas Paleontological Contributions, Paper 31, 7 p.
- Conkin, J. E. and Conkin, B. M., 1973, The paracontinuity and the determination of the Devonian-Mississippian boundary in the type Lower Mississippi area of North America: University of Louisville Studies in Paleontology and Stratigraphy No. 1, 34 p., 1 pl.
- Conkin J. E.. and Conkin, B. M., 1979, The Devonian-Mississippian and Kinderhookian boundaries in southern Indiana and northwestern Kentucky, in Conkin, J. E. and Conkin, B. M., eds., Devonian-Mississippian boundary in southern Indiana and northwestern Kentucky: Guidebook of Field Trip No. 7, Ninth International Congress of Carboniferous Stratigraphy and Geology, p. 46-52.
- Conkin, J. E., Conkin, B. M., and Lipchinsky, L. Z., 1980, Devonian black shale in the eastern United States: Part 1-southern Indiana, Kentucky, northern and eastern Highland Rim of Tennessee, and central Ohio; University of Louisville Studies in Paleontology and Stratigraphy No. 12, 63 p.
- Cooper, G. A., and Dutro, J. T., Jr., 1982, Devonian brachiopods of New Mexico: Bulletins of American Paleontology, vols. 82 and 83, 215 p., 45 pl.
- Crickmay, C. H., 1952, Discrimination of Late Upper Devonian: Journal of Paleontology, v. 26, no. 4, p. 585-609.

- Cross, A. T., 1982, Plant macrofossils of the Devonian-Mississippian black shales, eastern interior, U. S. A., a review: Conference on Sedimentology and Paleontology of mid-Continent Black Shales, [unpublished abstract], Cleveland, Ohio.
- Cross, A. T., and Hoskins, J. H., 1951, Paleobotany of the Devonian-Mississippian black shales: *Journal of Paleontology*, v. 25, no. 6, p. 713-728.
- Demaison, G. J., and Moore, G. T., 1980, Anoxic environments and oil source bed genesis: *American Association of Petroleum Geologists Bulletin*, v. 64, no. 8, p. 1179-1209.
- Dow, W. G., 1974, Application of oil-correlation and source-rock data to exploration in Williston Basin: *American Association of Petroleum Geologists Bulletin*, v. 58, no. 7, p. 1253-1262.
- Ettensohn, F. R., and Barron, L. S., 1981, Depositional model for the Devonian-Mississippian black shales of North America: A paleoclimatic-paleogeographic approach, in Roberts, T. G., ed., *Geological Society of America Cincinnati '81, Field Trip Guidebooks, Volume 2: Economic geology, structure*: American Geological Institute Washington, D. C., p. 344-361.
- Fuller, J. G. C. M., 1956, Mississippian rocks and oilfields in southeastern Saskatchewan: *Saskatchewan Department of Mineral Resources Report no. 19*, 51 p.
- Gerhard, L. C., Anderson, S. B., LeFever, J. A., and Carlson, C. G., 1982, Geological development, origin, and energy mineral resources of Williston Basin, North Dakota: *American Association of Petroleum Geologists Bulletin*, v. 66, no. 8, p. 989-1020.
- Girty, G. H., 1898, Description of a fauna found in the Devonian black shale of eastern Kentucky: *The American Journal of Science*, 4th ser. v. 5, art. 37, p. 384-395, 1 pl.
- Girty, G. H., 1939, Some linguloid shells from the Late Devonian and Early Carboniferous rocks of Pennsylvania and Ohio: *U. S. Geological Survey Professional Paper 193-C*, 67 p., 9 pl.
- Goddard, E. N., Trask, R. D., DeFord, R. K., Rove, O. N., Singewald, J. T., Jr., and Overbeck, R. M., 1948, *Rock Color Chart*: New York, The Geological Society of America.
- Green, Robert, 1962, Zonal relationships in lower Mississippian rocks of Alberta: *Journal of the Alberta Society of Petroleum Geologists*, v. 10, no. 6, p. 292-307.
- Grenda, J. C., 1977, Paleozoology of cores from the Tyler Formation (Pennsylvanian) in North Dakota, U. S. A.: unpublished dissertation, University of North Dakota, Grand Forks, N. D., 338 p.

- Grinnel, R. S., and Andrews, G. W., 1964, Morphologic studies of the brachiopod genus Composita: Journal of Paleontology, v. 38, no. 2, p. 227-248, 3 pl.
- Gutschick, R. C., 1962, Arenaceous foraminifera from oncolites in the Mississippian Sappington Formation of Montana: Journal of Paleontology, v. 36, no. 6, p. 1291-1304.
- Gutschick, R. C., McLane, Michael, and Rodriguez, Joaquin, 1976, Summary of Late Devonian-Early Mississippian biostratigraphic framework in western Montana, in 27th Annual Field Conference Guidebook, Tobacco Root Geological Society: Montana Bureau of Mines and Geology, Special Publication No. 73, p. 91-123.
- Gutschick, R. C., and Moreman, W. L., 1967, Devonian-Mississippian boundary relations along the cratonic margin of the U. S., in Oswald, D. H., ed., International Symposium on the Devonian System, Calgary, Alberta: Alberta Society of Petroleum Geologists, v. 2, p. 1009-1023.
- Gutschick, R. C., and Perry T. G., 1959, Sappington (Kinderhookian) sponges and their environment: Journal of Paleontology, v. 33, no. 6, p. 977-985.
- Gutschick, R. C., and Rodriguez, Joaquin, 1967, Brachiopod zonation and correlation of the Sappington Formation of western Montana: American Association of Petroleum Geologists Bulletin, v. 51, no. 4, p. 601-620.
- Gutschick, R. C., and Rodriguez, Joaquin, 1977, Late Devonian-Early Mississippian trace fossils and environments along the Cordilleran miogeosyncline, western U. S., in Crimes, T. P., and Harper, J. C., eds., Trace Fossils 2: Geological Journal Special Issue 9, Seel House Press, Liverpool, p. 195-208.
- Gutschick, R. C. and Rodriguez, Joaquin, 1979, Biostratigraphy of the Pilot Shale (Devonian-Mississippian) and contemporaneous strata in Utah, Nevada, and Montana: Brigham Young University Geological Studies, v. 26, pt. 1, p. 37-63.
- Gutschick, R. C., and Sandberg, C. A., 1970, Latest Devonian conchostracans along cordilleran miogeosyncline, Alberta, Montana, Utah, and Nevada [abs.]: American Association of Petroleum Geologists Bulletin, v. 54, no. 5, p. 849-850.
- Gutschick, R. C., Suttner, L. J., and Switek, M. J., 1962, Biostratigraphy of the transitional Devonian-Mississippian Sappington Formation of southwest Montana: 13th Annual Field Conference Guidebook, Billings Geological Society, p. 79-89.
- Hall, James, 1867, Descriptions and figures of the fossil Brachiopoda of the upper Helderberg, Hamilton, Portage, and Chemung Groups: New York Geological Survey, Natural History of New York, Paleontology, v. 4, pt. 1, 428 p., 63 pl.

- Hall, James, and Clarke, J. M., 1892, An introduction to the study of the genera of Paleozoic Brachiopoda: New York Geological Survey, Natural History of New York, Paleontology, v. 8, Brachiopoda, pt. 1 365 p.
- Häntzschel, Walter, 1975, Trace fossils and problematica, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part W, Supplement 1: Geological Society of America and University of Kansas Press, Lawrence, 269 p.
- Harker, Peter, and McLaren, D. J., 1958, The Devonian-Mississippian boundary in the Alberta Rocky Mountains, in Goodman, A. J., ed., Jurassic and Carboniferous of western Canada: American Association of Petroleum Geologists, John A. Allen Memorial Volume, p. 244-253.
- Harker, Peter, and Raasch, G. O., 1958, Megafaunal zones in the Alberta Mississippian and Permian, in Goodman, A. J., ed., Jurassic and Carboniferous of western Canada: American Association of Petroleum Geologists, John A. Allen Memorial Volume, p. 216-231.
- Hayes, M. D., 1984, Conodonts of the Bakken Formation (Devonian and Mississippian), Williston Basin, North Dakota: unpublished M. S. thesis, University of North Dakota, Grand Forks, 178 p., 3 pl.
- Hayes, M. D., 1985, Conodonts of the Bakken Formation (Devonian and Mississippian), Williston Basin, North Dakota: The Mountain Geologist, v. 22, no. 2, p. 64-77, 3 pl.
- Heckel, P. H., and Witzke, B. J., 1979, Devonian world paleogeography determined from distribution of carbonates and related lithic palaeoclimatic indicators, in House, M. R., Scrutton, C. T., and Basset, M. G., eds., The Devonian system: Palaeontological Association Special Papers in Palaeontology, no. 23, p. 99-123.
- Hester, T. C., and Schmoker, J. W., 1983, Organic carbon in the Bakken Formation, U. S. portion of the Williston basin: American Association of Petroleum Geologists Bulletin, v. 67, no. 12, p. 2165-2174.
- Hester, T. C., and Schmoker, J. W., 1985, Selected physical properties of the Bakken Formation, North Dakota and Montana part of the Williston Basin: U. S. Geological Survey, Oil and Gas Investigations Chart, chart OC-126, 7 p., 15 maps
- Hill, Dorothy, 1981, Tabulata, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part F, Coelenterata, Supplement 1; Rugosa and Tabulata, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. F506-F668.
- Holland, F. D., Jr., 1952, Stratigraphic details of lower Mississippian rocks of northeastern Utah and southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 1697-1734.



- Hose, R. K., 1966, Devonian stratigraphy of the Confusion Range, west-central Utah: U. S. Geological Survey Professional Paper 550-B, p. B36-B41.
- House, M. R., 1962, Observations on the Ammonoid succession of the North American Devonian: *Journal of Paleontology*, v. 36, no. 2, p. 247-284.
- Hyde, J. E., 1953, Mississippian formations of central and southern Ohio: Ohio Division of the Geological Survey Bulletin 51, 355 p., 54 pl.
- International Commission on Zoological Nomenclature, 1928, Opinion 100: *Smithsonian Miscellaneous Collections*, v. 73, no. 5, p. 369-396.
- Johnson, J. G., and Reso, Anthony, 1966, Brachiopods from the Pilot Shale (Devonian) in southeastern Nevada: *Journal of Paleontology*, v. 52, no. 6, p. 125-129, 1 pl.
- Kents, Paul, 1959, Three Forks and Bakken stratigraphy in west-central Saskatchewan: Saskatchewan Department of Mineral Resources, Report 37, 39 p.
- Kepferle, R. C., and Roen, J. B., 1981, Chattanooga and Ohio Shales of the southern Appalachian Basin, in Roberts, T. G., ed., *Geological Society of America Cincinnati '81, Field Trip Guidebooks, Volume 2: Economic geology, structure*; American Geological Institute, p. 259-362.
- Klapper, Gilbert, and Furnish, W. M., 1962, Devonian-Mississippian Englewood Formation in the Black Hills, South Dakota: *American Association of Petroleum Geologists Bulletin*, v. 46, no. 11, p. 2071-2078.
- Knechtel, M. M., Smedley, J. E., and Ross, R. J., Jr., 1954, Little Chief Canyon Member of the Lodgepole Limestone of Early Mississippian age in Montana: *American Association of Petroleum Geologists Bulletin*, v. 38, no. 11, p. 2395-2411.
- Knight, J. B., Batten, R. L., and Yochelson, E. L., 1960, Order Archaeogastropoda, in Moore, R. C., ed., *Treatise on invertebrate paleontology, Part I, Mollusca 1: Geological Society of America and University of Kansas Press, Lawrence*, p. I171-I310.
- Knight, J. B., and Cox, L. R., 1960, Family Loxonematidae, in Moore, R. C., ed., *Treatise on invertebrate paleontology, Part I, Mollusca 1: Geological Society of America and University of Kansas Press, Lawrence*, p. I311-I312.
- Kohlberger, William, 1983, Black shales: *Paleobiology* v. 9, no. 1, p. 9-11.
- Krystinik, K. B., and Charpentier, R. R., 1984, Developing an oil generation model for resource assessment of the Bakken Formation: U. S. Geological Survey, Open-File Report 84-694, 23 p.

- Kume, Jack, 1963, The Bakken and Englewood Formations of North Dakota and northwestern South Dakota: North Dakota Geological Survey Bulletin 39, 87 p.
- La Roque, Aurèle, and Marple, M. F., 1955, Ohio fossils: Ohio Division of Geological Survey, Bulletin 54, 152 p.
- LeFever, J. A., and Anderson, S. B., 1984, A little known carbonate reservoir within the lower Lodgepole Formation, northwestern North Dakota, in Lorsong, J. A. and Wilson, M. A., Oil and gas in Saskatchewan: Saskatchewan Geological Society Special Publication No. 7, p. 31-43.
- Lethiers, Francis, 1981, Ostracodes du Dévonien terminal de l'ouest du Canada: Systématique, biostratigraphie et paléoécologie: Geobios Special Memoir no. 5, 234 p., 26 pl.
- Lineback, J. A., and Davidson, M. L., 1982, The Williston Basin--sediment-starved during the Early Mississippian, in Kaldi, John, and Christopher, J. E., Fourth International Williston Basin Symposium, Saskatchewan Geological Society and North Dakota Geological Society: Saskatchewan Geological Society Special Publication No. 6, p. 125-130.
- Macauley, George, Penner, D. G., Procter, R. M., and Tisdall, W. H., 1964, Carboniferous, in McCrossan, R. G., ed., Geologic history of western Canada: Alberta Society of Petroleum Geologists, p. 89-102.
- MacDonald, G. H., 1956, Subsurface stratigraphy of the Mississippian rocks of Saskatchewan: Geological Survey of Canada Memoir 282, 46 p.
- Macqueen, R. W., and Sandberg, C. A., 1970, Stratigraphy, age, and interregional correlation of the Exshaw Formation, Alberta Rocky Mountains: Bulletin of Canadian Petroleum Geology, v. 18, no. 1, p. 32-66.
- Mathews, R. D., 1983, Foerstia from the Antrim Shale (Devonian) of Michigan: Geology, v. 11, no. 6, p. 327-330.
- McCabe, H. R., 1959, Mississippian stratigraphy of Manitoba: Province of Manitoba, Department of Mines and Natural Resources Publication 58-1, 77 p.
- McLaren, D. J., 1965, Family Trigonirhynchiidae, in Moore, R. C., ed Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. H559-H562.
- McLaren, D. J., 1965, Genus Rugaltarostrum, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. H583.

- Meissner, F. F., 1978, Petroleum geology of the Bakken Formation, Williston Basin, North Dakota and Montana: Williston Basin Symposium, 24th Annual Field Conference Guidebook, Montana Geological Society, p. 207-231.
- Miller, A. K., Furnish, W. M., and Schindewolf, O. H., 1957, Paleozoic Ammonoidea, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part L, Mollusca 4: Geological Society of America and University of Kansas Press, Lawrence, p. L11-L80.
- Mitchell, J. G., and Maher, J. C., 1957, Suggested abbreviations for lithologic descriptions: American Association of Petroleum Geologists Bulletin, v. 41, no. 9, p. 2103-2107.
- Moore, R. C., and Harrington, H. J., 1956, Suborder Conchopeltina, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part F, Coelenterata, vol. 1: Geological Society of America and University of Kansas Press, Lawrence, p. F57-F76.
- Muir-Wood, H. M., 1962, On the morphology and classification of the brachiopod suborder Chonetoidea: British Museum of Natural History, London, 132 p., 16 pl.
- Muir-Wood, H. M., and Cooper, G. A., 1960, Morphology, classification, and life habits of the Productoidea (Brachiopoda): Geological Society of America Memoir 81, 447 p., 135 pl.
- Muir-Wood, H. M., and Williams, Alwyn, 1965, Suborder Strophomenidina, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 1: Geological Society of America and University of Kansas Press, Lawrence, p. H361-H403.
- Nelson, S. J., 1961, Mississippian faunas of Western Canada: Geological Association of Canada Special Paper no. 2, 39 p., 29 pl.
- Nordquist, J. W., 1953, Mississippian stratigraphy in northern Montana: Billings Geological Society 4th Annual Field Conference Guidebook, p. 68-82.
- Penner, D. G., 1958, Mississippian stratigraphy of the southern Alberta Plains, in Goodman, A. J., ed., Jurassic and Carboniferous of western Canada: American Association of Petroleum Geologists, John Andrew Allen Memorial Volume, p. 260-288.
- Pitrat, C. W., 1965, Suborder Spiriferidina, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. H667-H728.

- Price, L. C., Ging, Tom, Daws, Ted, Love, Alonza, Pawlewicz, Mark, and Anders, Don, 1984, Organic metamorphism in the Mississippian-Devonian Bakken Shale, North Dakota portion of the Williston Basin, in Woodward, Jane, Meissner, F. F., and Clayton, J. L., Hydrocarbon source rocks of the greater Rocky Mountain Region: Rocky Mountain Association of Geologists, Denver, CO., p. 83-125
- Raasch, G. O., 1956, Late Devonian and/or Mississippian faunal succession in the Stettler Area, Alberta: Bulletin of the Alberta Society of Petroleum Geologists, v. 4, no. 8, p. 112-118.
- Robinson, G. D., 1963, Geology of the Three Forks Quadrangle, Montana: U. S. Geological Survey Professional Paper 370, 140 p.
- Rodriguez, Joaquin, and Gutschick, R. C., 1967, Brachiopods from the Sappington (Devonian-Mississippian) Formation of western Montana: Journal of Paleontology v. 41, no. 2, p. 364-384., pls. 41-44.
- Rodriguez, Joaquin, and Gutschick, R. C., 1970, Late Devonian-Early Mississippian ichnofossils from western Montana and northern Utah, in Crimes, T. P., and Harper, J. C., eds., Trace fossils: Geological Journal, Special Issue 3, Seel House Press, Liverpool, p. 407-438, 10 pl.
- Rodriguez, Joaquin, and Gutschick, R. C., 1975, Epibiontic relationships on a Late Devonian algal bank: Journal of Paleontology v. 49, no. 6, p. 1112-1120, 5 text-figs.
- Rodriguez, Joaquin, and Gutschick, R. C., 1978, A new shallow water Schizophoria from the Leatham Formation (Late Famennian), northeastern Utah: Journal of Paleontology, v. 52, no. 6, p. 1346-1355, 1 pl.
- Romer, A. S., 1945, Vertebrate paleontology: University of Chicago Press, Chicago, 687 p.
- Rowell, A. J., 1965, Class Inarticulata, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 1: Geological Society of America and University of Kansas Press, Lawrence, p. H260-H296.
- Rowley, R. R., 1908, Geology of Pike County: Missouri Bureau of Geology and Mines, v. 8, 2nd ser., 122 p., 20 pl.
- Sandberg, C. A., 1962, Correlation of Devonian and lowermost Mississippian rocks between outcrops in western and central Montana and the Williston Basin in eastern Montana: 13th annual Field Conference Guidebook, Billings Geological Society, p. 33-34.
- Sandberg, C. A., 1963, Dark shale unit of Devonian and Mississippian age in northern Wyoming and southern Montana: U. S. Geological Survey Professional Paper 475-C, article 64, p. C17-C20.

- Sandberg, C. A., 1964, Pre-Cambrian to Mississippian paleotectonics of the southern Williston basin: Third International Williston Basin Symposium, Billings Geological Society, North Dakota Geological Society, and Saskatchewan Geological Society, p. 37-38.
- Sandberg, C. A., 1965, Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks Formations of southwestern Montana and northwestern Wyoming: U. S. Geological Survey Bulletin 1194-N, p. N1-N8.
- Sandberg, C. A., 1967, Exshaw Formation of Devonian and Mississippian age in northwestern Montana, in Changes in stratigraphic nomenclature by the U. S. Geological Survey, 1967: U. S. Geological Geological Survey Bulletin 1253-A, p. A39-A41.
- Sandberg, C. A., 1976, Conodont biofacies of the Late Devonian Polygnathus styriacus zone in the western U. S.: Geological Association of Canada, Special Paper 15, p. 171-185.
- Sandberg, C. A., 1979, Devonian and lower Mississippian conodont zonation of the Great Basin and Rocky Mountains, in Sandberg, C. A., and Clark, D. L., eds., Conodont biostratigraphy of the Great Basin and Rocky Mountains: Brigham Young University Geology Studies, v. 26, pt. 3, p. 87-106.
- Sandberg, C. A., 1983, The Devonian-Carboniferous boundary in North America [abs.]: Geological Society of America, Abstracts with Programs, v. 15, no. 4, p. 315.
- Sandberg, C. A., and Gutschick, R. C., 1969, Stratigraphy and conodont zonation of type Leatham Formation (Devonian-Mississippian), Bear River Range, Utah [abs.]: Geological Society of America, Abstracts with Programs, v. 11, pt. 5, p. 70-71.
- Sandberg, C. A., and Gutschick, R. C., 1979, Guide to conodont biostratigraphy of upper Devonian and Mississippian rocks along the Wasatch Front and Cordilleran Hingeline, Utah, in Sandberg, C. A., and Clark D. L., eds., Conodont biostratigraphy of the Great Basin and the Rocky Mountains: Brigham Young University Geology Studies, v. 26, pt. 3, p. 107-133.
- Sandberg, C. A., Gutschick, R. C., Johnson, J. G., Poole, F. G., and Sando, W. J., 1983, Middle Devonian to Late Mississippian geological history of the Overthrust belt region, western United States: Rocky Mountain Association of Geologists, Geologic Studies of the Cordilleran Thrust Belt, v. 2, p. 691-719.
- Sandberg, C. A., and Hammond, C. R., 1958, Devonian system in the Williston Basin and central Montana: American Association of Petroleum Geologists Bulletin, v. 42, no. 10, p. 2293-2334.

- Sandberg, C. A., and Klapper, Gilbert, 1967, Stratigraphy, age, and paleotectonic significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana: U. S. Geological Survey Bulletin 1251-B, p. B1-B70.
- Sandberg, C. A., and Mapel, W. J., 1967, The Devonian of the northern Rocky Mountains and plains, in Oswald, D. H., ed., International Symposium on the Devonian System, Volume 1: Alberta Society of Petroleum Geologists, p. 843-877.
- Sandberg, C. A., and Poole, F. G., 1977, Conodont biostratigraphy and depositional complexes of the upper Devonian cratonic platform and continental shelf rocks in the western U. S., in Murphy, M. A., Berry, W. B. N., and Sandberg, C. A., eds., Western North America: Devonian: University of California, Riverside, Museum Contributions no. 4, p. 144-180.
- Sandberg, C. A., Poole, F. G., and Gutschick, R. C., 1980, Devonian and Mississippian stratigraphy and conodont zonation of the Pilot and Chainman Shales, Confusion Range, Utah, in Fouch, T. D., and Magathan, E. R., eds., Paleozoic paleogeography of west-central U. S.: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Paleogeography Symposium 1, p. 71-79.
- Sandberg, C. A., Streel, Maurice, and Scott, R. A., 1972, Comparison between conodont zonation and spore assemblages at the Devonian-Carboniferous boundary in the western and central U. S. and Europe: 7th International Congress for Stratigraphy and Geology of the Carboniferous, Krefeld, v. 1, p. 179-203, 4 pl.
- Sando, W. J., 1984, Siringoporid corals: Guides to the stratigraphy of upper Paleozoic rocks in the Western Interior region: U. S. Geological Survey Open File Report 84-80, 29 p.
- Sando, W. J., and Dutro, J. T., Jr., 1974, Type sections of the Madison Group (Mississippian) and its subdivisions in Montana: U. S. Geological Survey Professional Paper 842, 22 p.
- Sando, W. J., Mamet, B. L., and Dutro, J. T., 1969, Carboniferous megafaunal and microfaunal zonation in the northern Cordillera of the U. S.: U. S. Geological Survey Professional Paper 613-E, p. E1-E25.
- Sartenaer, Paul, 1961a, Late Upper Devonian (Famennian) rhynchonelloid brachiopods: Bulletin of the Institut royal des Sciences naturelles de Belgique, t. 37, no. 24, 10 p., 2 pl.
- Sartenaer, Paul, 1961b, Redescription of Leiorhynchus quadracostatus (Vanuxem), type species of Leiorhynchus Hall, 1860 (Rhynchonellacea): Journal of Paleontology, v. 35, no. 5, p. 963-976.
- Sartenaer, Paul, 1961c, Etude nouvelle, en deux parties, du genre Camarotoechia Hall et Clarke, 1893. Première partie: Atrypa congregata Conrad, espèce-type: Bulletin of the Institut royal des Sciences naturelles de Belgique, t. 37, no. 22, 11 p., 1 pl.

- Sartenaer, Paul, 1967, Famennian Rhynchonellid brachiopod genera as a tool for correlation, in Oswald, D. H., ed., International Symposium on the Devonian System, Calgary, Alberta: Canadian Association of Petroleum Geologists, v. 2, p. 1043-1060.
- Sartenaer, Paul, 1969, Late Upper Devonian (Famennian) rhynchonellid brachiopods from western Canada: Geological Survey of Canada, Department of Energy, Mines, and Resources Bulletin 169, 269 p., 19 pl.
- Schindewolf, O. H., 1959, Adolescent cephalopods from the Exshaw Formation of Alberta: Journal of Paleontology, v. 33, no. 6, p. 971-976, 2 pl.
- Schmidt, Herta, 1965, Family Wellerellinae, in Moore, R. C., ed., Treatise on invertebrate paleontology, Part H, Brachiopoda, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. H590-H592.
- Schopf, J. M., and Schwietering, J. F., 1970, The Foerstia zone of the Ohio and Chattanooga Shales: U. S. Geological Survey Bulletin 1294-H, 15 p., 2 pl.
- Schram, F. R., 1969, The stratigraphic distribution of the Paleozoic Eumalacostraca: Fieldiana, Geology, v. 12, no. 13, p. 213-234.
- Schram, F. R., Feldmann, R. M., and Copeland, M. J., 1978, The Late Devonian Palaeopalanonidae and the earliest decapod crustaceans: Journal of Paleontology, v. 52, no. 6, p. 1375-1387.
- Scott, H. W., 1961, Order Leperditicopoda, in, Moore, R. C., ed., Treatise on invertebrate paleontology, Part Q, Arthropoda 3: Geological Society of America and University of Kansas Press, Lawrence, p. Q103-Q109.
- Scott, A. J., and Collinson, C. W., 1961, Conodont faunas from the Louisiana and McCraney Formations of Illinois, Iowa, and Missouri: Kansas Geological Society Guidebook, 26th Annual Field Conference, northeastern Missouri and west-central Illinois, p. 100-109.
- Shaw, A. B., 1962, Rhynchonellid brachiopods and a Torynifer from the Madison Group (Mississippian): Journal of Paleontology, v. 36, no. 4 p. 630-637, 2 pl.
- Shimer, H. W., and Shrock, R. R., 1944, Index fossils of North America: American Technology Press, Massachusetts Institute of Technology, New York, John Wiley and Sons, 837 p., 303 pl.
- Stainbrook, M. A., 1950, The fauna and correlation of the McCraney Limestone of Iowa and Illinois: American Journal of Science, v. 248, p. 194-213.

- Swartz, J. H., 1929, The age and stratigraphy of the Chattanooga Shale in northeastern Tennessee and Virginia: *American Journal of Science*, 5th ser., v. 17, p. 431-448.
- Tasch, Paul, 1963, Paleolimnology, part 3--Marion and Dickinson Counties, Kansas, with additional sections in Harvey and Sedgwick Counties: stratigraphy and biota: *Journal of Paleontology*, v. 37, no. 6, p. 1233-1251.
- Tasch, Paul, 1969, Branchiopoda, in Moore, R. C., ed., *Treatise on invertebrate paleontology*, Part R, Arthropoda 4, v. 1: Geological Society of America and University of Kansas Press, Lawrence, p. R128-R191.
- Teichert, Curt, and Moore, R. C., 1964, Classification and stratigraphic distribution [of cephalopods], in Moore, R. C., ed., *Treatise on invertebrate paleontology*, Part K, Mollusca 3: Geological Society of America and University of Kansas Press, Lawrence, p. K94-K106.
- Twenhofel, W. H., 1939, Environments of origin of black shales: *American Association of Petroleum Geologists Bulletin*, v. 23, no. 8, p. 1178-1198.
- Warren, P. S., 1937, Age of the Exshaw Shale in the Canadian Rockies: *American Journal of Science*, ser. 5, v. 33, p. 454-457.
- Webster, R. L., 1982, Analysis of petroleum source rocks of the Bakken Formation (Devonian-Mississippian) in North Dakota: unpublished M. S. thesis, University of North Dakota, Grand Forks, 150 p.
- Webster, R. W., 1984, Petroleum source rocks and stratigraphy of the Bakken Formation in North Dakota, in Woodward, Jane, Meissner, F. F., and Clayton, J. L., eds., *Hydrocarbon source rocks of the greater Rocky Mountain Region*: Rocky Mountain Association of Geologists, Denver, p. 57-81.
- Weller, Stuart, 1914, The Mississippian Brachiopoda of the Mississippi Valley Basin, parts 1 and 2: *Illinois State Geological Survey Monograph* 1, 508 p., 83 pl.
- Williams, Alwyn, 1965, Suborder Strophomenidina, in Moore, R. C., ed., *Treatise on invertebrate paleontology*, Part H, Brachiopoda, v. 2: Geological Society of America and University of Kansas Press, Lawrence, p. H362-H412.
- Williams, J. A., 1974, Characterization of oil types in the Williston Basin: *American Association of Petroleum Geologists Bulletin*, v. 58, no. 7, p. 1243-1252.
- Williams, J. S., 1943, Stratigraphy and fauna of the Louisiana Limestone of Missouri: *U. S. Geological Survey Professional Paper* 203, 133 p., 4 pl.



- Wilson, B. J., 1983, Petroleum production and petroleum geology of the Bakken Formation, Williston Basin, North Dakota: The Compass of Sigma Gamma Epsilon, v. 60, no. 4, p. 99-110.
- Ziegler, Willi, and Sandberg, C. A., 1984, Palmatolepis-based revision of upper part of standard Late Devonian conodont zonation, in Clark, D. L., ed., Conodont biofacies and provincialism: Geological Society of America, Special Paper 196, p. 179-194.
-